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IMPROVED AIR POLLUTION CONTROL FOR A KRAFT RECOVERY BOILER

MODIFIED RECOVERY BOILER NUMBER 3

HOERNER WALDORF CORPORATION

PREPARED FOR
NATIONAL ENVIRONMENTAL RESEARCH CENTER

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The report gives results of an intensive emission testing program to verify the anticipated reduction in both gaseous and particulate air pollutants caused by the conversion of a conventional kraft recovery boiler (utilizing direct contact evaporation) to a new controlled-odor design that eliminates direct contact evaporation. It documents both the cost and emission control capability of the modification, the first known of this type in the U.S. The program also investigated major process variables that affect kraft recovery boiler operation and the emissions resulting therefrom in order to establish boiler operating conditions to minimize emissions. Investigated were: boiler loading, liquor sulfidity, air flow, air distribution, and liquor solids concentration. Test data was analyzed statistically by computer, using the multiple regression analysis technique. Particulate emissions were primarily affected by and directly proportional to the amount of black liquor solids burned in the recovery furnace (boiler loading). SO2 emissions were primarily dependent on the sulfidity level of the cooking liquor being recovered. Total reduced sulfur (TRS) emissions were primarily affected by excess oxygen levels, with an increase in oxygen resulting in a decrease in TRS. The modification of the recovery boiler was successful; it reduced both TRS and particulate emissions sufficiently to meet Montana state emission standards.

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This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The purpose of this contract was to document the cost of and the emission control capability associated with the conversion of a conventional kraft recovery boiler, which utilized direct contact evaporation, to a new "controlled odor" design that eliminates the use of direct contact evaporation.

The evaluation of this modification, the first known conversion of this type in the United States, was accomplished by means of an intensive emission testing program to verify the anticipated reduction in air pollutants, both gaseous and particulate.

The testing program also investigated major process variables that affect the operation of a kraft recovery boiler and the emissions resulting therefrom in order to establish the proper conditions of boiler operation required to minimize emissions. Variables investigated included boiler loading, liquor sulfidity, air flow, air distribution, and liquor solids concentration.

The analysis of test data collected was accomplished statistically with the aid of an IBM 370 computer using the multiple regression analysis technique. Particulate emissions were found to be primarily affected by and directly proportional to the amount of black liquor solids burned in the recovery furnace (boiler loading). The emissions of SO_2 were primarily dependent on the sulfidity level of the cooking liquor being recovered, Total reduced sulfur (TRS) emissions were primarily affected by excess oxygen levels, with an increase in oxygen resulting in a decrease in TRS.

The modification of the recovery boiler was successful in that the emissions of both TRS and particulates were sufficiently reduced to enable the unit to meet Montana State emission standards.

This report was submitted in fulfillment of Demonstration Grant Contract No. 68-02-0247 by the Hoerner Waldorf Corporation under the sponsorship of the Environmental Protection Agency. Work was completed as of February, 1974.

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Special thanks is due to Mr. Sheldon D. Sorensen, Manager of Management Science for Hoerner Waldorf, for his invaluable assistance in the statistical analysis of the test data collected.

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SECTION I

CONCLUSIONS

Phase I of the air pollution abatement plan for the Hoerner Waldorf pulp mill in Missoula, Montana,involved the conversion of a conventional kraft recovery boiler with a nominal capacity of 470 tons per day to a "controlled odor" design unit by the elimination of the direct contact evaporator.

To successfully accomplish this conversion,a 20 month project was undertaken at a capital cost of $2,600,000. A black liquor evaporator concentrator, a second boiler economizer, and a dry bottom, high efficiency (99.125%) electrostatic precipitator were installed as part of the overall program.

This project demonstrated that, under practical operating conditions, a modified recovery boiler can maintain sufficiently low emissions of both TRS and particulates to meet the Montana State Emission Standards of 17.5 ppm TRS (daily average) and 45.3 lb/hr. of particulate matter. Previous daily TRS emissions averaged over 400 ppm, ranging from 100 to 700 ppm. Daily TRS emissions from the new system average less than 10 ppm and range from essentially zero to 25 ppm. Particulate emissions have been reduced from 6000 lb/day to 1000 lb/day, a reduction of 83%. The moisture content of the flue gas has been reduced more than 40%, which has practically eliminated the visible plume from the recovery stack.

A review of operating costs before and after system modifications reveals increased total annual costs for the modified system amounting to $169,000. This is particularly true in the case of chemical makeup where the increased usage of caustic soda has resulted in an annual cost increase of $86,000. A slight reduction in horsepower resulted from the system modifications but these cost savings were overshadowed by the increased cost for boiler feedwater. Maintenance costs for the No. 3 modified recovery system increased by $70,000 per year to insure that emissions remain at a minimum level.

An intensive testing program was carried out on No. 3 recovery boiler to investigate the cause and effect relationships between process variables and resultant emissions, both gaseous and particulate. A total of 126 sets of data were collected in order to thoroughly investigate the effect of boiler loading, liquor sulfidity, air distribution, and excess oxygen on TRS, SO_2, and stack particulate. The analysis of data was accomplished statiscally with the aid of an IBM system 370 computer using Multiple Regression Analysis.

Both boiler exit dust load and stack particulate were found to be almost entirely dependent on boiler loading, the amount of black liquor solids burned in the recovery furnace . At design loading, boiler exit dust load averaged 4270 lb/hr. Stack particulate averaged 44 lb/hr. at 100% boiler loading.

Both TRS and SO_2 emissions were affected by the sulfidity level of the liquor being burned. TRS emissions were found to be primarily affected by the excess oxygen level maintained at the boiler exit. The test data indicated that at least 1.5% excess oxygen must be maintained to insure that daily average TRS emissions do not exceed 17.5 ppm.

SO_2 emissions were primarily effected by the sulfidity level maintained in the liquor. The regression analysis of all test data indicated that average daily SO_2 emissions can be maintained below 100 ppm if the sulfidity level does not exceed 31%.

SECTION II

RECOMMENDATIONS

The results obtained from this EPA-supported investigation of recovery boiler operation, and the cause and effect relationships between operating variables and the resultant particulate and gaseous emissions, suggest that additional planned studies would be helpful to shed further light on the complex relationships that exist in recovery boiler operation. This is supported by the fact that emission variability was not adequately correlated by the process variables included in this study. Additional process variables remaining to be investigated when reliable monitoring instruments are developed in the future include smelt bed height and bed temperature in the recovery furnace itself.

All of the test data resulting from this EPA contract could be utilized to confirm the theoretical models that have been constructed by others. In this manner, a better understanding of actual kraft recovery furnace operation would result.

SECTION III

INTRODUCTION

(SCOPE OF WORK)

An integral part of the Kraft process is the chemical recovery system which chemically converts the spent cooking liquor, known in the industry as black liquor, into reusable chemicals for the cooking or digesting process. The chemical recovery furnace is the heart of the recovery system and is a potential major source of air pollution. The work described in this paper concerns the first known conversion in the United States of a conventional recovery system, having a direct contact evaporator, to a controlled odor or low emission system in which the major source of malodorous emissions is eliminated.

The purpose of this contract was to document the cost and emission control capability associated with the conversion of a conventional kraft recovery boiler, which utilized direct contact evaporation, to a new "controlled odor" design that eliminates the use of direct contact evaporation. The evaluation of this modification in reducing the emission of air pollutants has been accomplished by means of a detailed emission testing program and the reporting of operational experience. Also, the testing program undertaken has established the necessary conditions of boiler operation required to minimize the emission of reduced sulfur compounds (known as TRS), sulfur dioxide, and particulates in both new and converted furnaces of this type. The program has also defined the capabilities of the new furnace system design.

This program, conducted by the Hoerner Waldorf Corporation and partially funded by an EPA Demonstration Grant, documents the successful modifications made to a kraft recovery system to improve emission control at the company's pulp mill located in Missoula, Montana. The three basic, inter-related areas investigated in the overall testing program, carried out on the No. 3 recovery boiler were:

1. Process control and monitoring of recovery boiler operation.
2. Monitoring of boiler and stack emissions.
3. Summary of operating experience and documentation of costs, both capital and operational.

PROCESS CONTROL AND MONITORING

The contractor investigated the anticipated major process variables that affect the operation of the kraft recovery boiler and the emissions resulting therefrom in order to develop the proper control of recovery boiler operation needed to minimize stack emissions. The variables investigated included the following:

Boiler Loading (Liquor Feed)
Sulfidity of Product Liquor
Air Flows

Air Distribution
Black Liquor Solids Concentration
Black Liquor Temperature
Feed Nozzle Pressure
Boiler Windbox Pressure
Salt Cake Addition Rates

PROCESS EMISSION SOURCE MONITORING

Recovery boiler and stack testing was carried out to establish the level of various emissions from the furnace. Measurements were made of sulfur dioxide (SO_2), reduced sulfur compounds (TRS), and particulates,as well as the physical properties needed to characterize the gas stream such as flow volume, temperature, moisture content, etc. The testing program consisted of three parts carried out sequentially in time.

Part I - The contractor (Hoerner Waldorf Corporation) first established the base-line emissions from the No. 3 recovery boiler before the unit was physically modified to reduce these emissions. All test data available regarding the degree of air pollution in existence prior to system modification was made available to this study.

Part II - An extensive emissions testing program was conducted on the No. 3 recovery boiler at Missoula following conversion of the system. Relationships were developed between air pollutant emissions and process variables such as sulfidity, boiler loading, excess air in the furnace and the ratios of primary, secondary, and tertiary air. Various boiler loadings were investigated (75%, 100%, and 110%) to demonstrate how emissions vary with furnace loading. Optimization of operating conditions to minimize stack emissions was attempted for each boiler load condition and demonstrated for a sufficient duration of time (12 to 24 hours) to insure stable operations.

Part III - No. 3 recovery boiler accounts for only about 40% of the total black liquor being processed at the Missoula mill. The overall emission control program also included the construction of a new No. 4 recovery boiler which was to be operational by the Fall of 1972. Once stable operation of this boiler has been attained, an emissions testing program similar to that conducted on No. 3 recovery boiler is planned. It will then be possible to rebalance the entire recovery system to optimize the overall recovery operation and thus minimize air emissions from the whole mill.

DOCUMENTATION OF COST AND OPERATING EXPERIENCE

The contractor agreed to report design detail and complete capital and operating costs associated with both No. 3 and No. 4 recovery boilers, and also to document operating experience with the new systems up to the time of contract completion.

This report presents information relative to Parts I and II of the overall program. A second report covering Part III will be prepared upon the completion of the testing program for No. 4 recovery boiler. It is anticipated this work will be completed by July 1, 1974.

SECTION IV

DESCRIPTION OF KRAFT PROCESS

The Kraft pulping process utilizes a cooking liquor consisting of caustic soda and sodium sulfide to delignify wood chips and sawdust and thereby produce a high strength pulp fiber at a relatively high yield from wood. Recovery of the cooking chemicals from kraft spent (black) liquor is essential for this process to be economically attractive and acceptable from a pollution standpoint. This is accomplished by spraying concentrated black liquor (60-65% solids content) into a recovery furnace where the organic material is burned and an inorganic smelt of sodium carbonate and sodium sulfide forms and is recovered.

The liquor sprayed into the furnace collects on the walls, dries, burns, and falls onto the bed at the bottom of the furnace. The organic material in the liquor burns off in the bed under reducing conditions maintained with limited oxygen from the admission of primary air into the furnace. Sulfur compounds in the smelt bed,including fresh makeup salt cake (Na_2SO_4),are reduced to sodium sulfide. The balance of the sodium compounds are converted to sodium carbonate. Molten smelt, a mixture of sodium sulfide and sodium carbonate, is discharged continuously from the bottom of the furnace through two water-cooled spouts into the dissolving tank where it reacts with water (weak wash) to form green liquor. This liquor is then reacted with slaked lime (calcium hydroxide), converting the green liquor to white (cooking) liquor. The latter is a mixture of sodium sulfide and sodium hydroxide used in the cooking process.

The calcium carbonate reaction by-product (known as lime mud) is settled out, dewatered and burned in a lime kiln to recover lime in the form of calcium oxide which is then returned to the process to take part in the reaction with green liquor. The flow sheet for this chemical process is illustrated in Figure 1.

To replenish the chemicals lost in the pulping process, salt cake (sodium sulfate) is added to the concentrated black liquor before it is sprayed into the furnace. In addition, some caustic soda is added to white liquor to balance the makeup requirements of both sodium and sulfur.

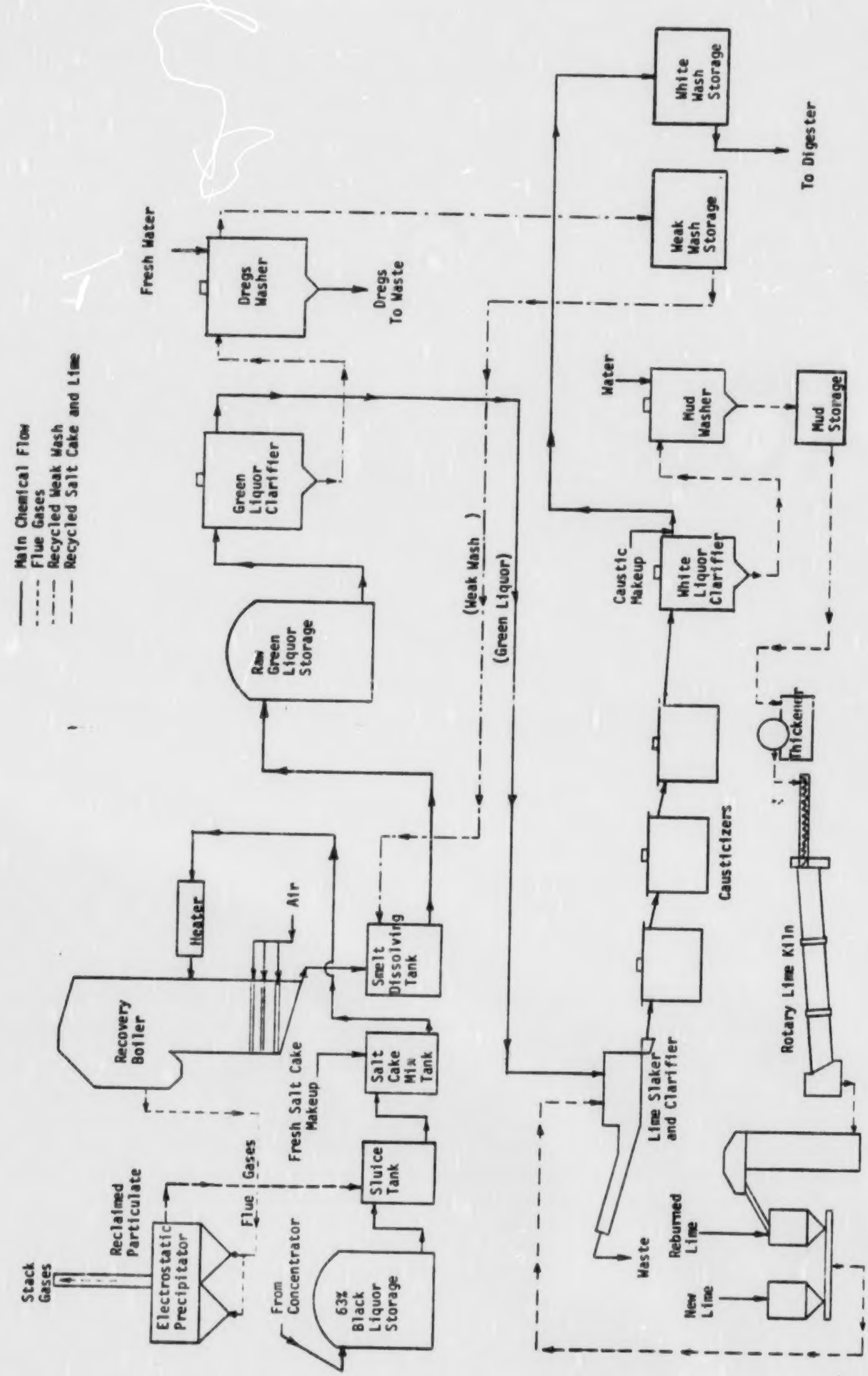

Main Chemical Flow
Flue Gases
Recycled Weak Wash
Recycled Salt Cake and Lime
Stack Gases
Reclaimed Particulate
Electrostatic Precipitator
Flue Gases
From Concentrator
63% Black Liquor Storage
Sluice Tank
Fresh Salt Cake Makeup
Salt Cake Mix Tank
Recovery Boiler
Heater
Air
Smelt Dissolving Tank
Raw Green Liquor Storage
Green Liquor Clarifier
Fresh Water
Dregs Washer
Dregs To Waste
(Weak Wash)
(Green Liquor)
Weak Wash Storage
White Wash Storage
To Digester
Water
Mud Washer
Mud Storage
Caustic Makeup
White Liquor Clarifier
Causticizers
Thickener
Rotary Lime Kiln
Lime Slaker and Clarifier
Waste
Reburned Lime
New Lime

Figure 1 Recovery and causticizing flow sheet

SECTION V

PROBLEM DEFINITION

The Hoerner Waldorf pulp mill located in Missoula, Montana is fairly representative of a typical kraft pulp mill. The plant, built in 1957, has undergone major expansions in 1960 and 1966. The Kraft process is used to produce the pulp for 1000 tons/day of linerboard and 150 tons/day of baled bleached pulp. The mill operates primarily on purchased wood waste obtained from some forty-five wood product operations (lumber and plywood plants) located in Montana and Idaho. Sawmill waste chips, sawdust and hogged fuel (primarily bark waste) are utilized at the Missoula mill, the latter as a fuel to generate steam and power.

The mill is located 15 miles west of Missoula in a large mountain valley where temperature inversions are a common occurrence. Unfortunately, the local topography and climatic conditions result in warm high air holding down the colder valley air, trapping air-polluting substances emitted from both home and industry.

The predominant wood species utilized at Missoula are ponderosa pine, Douglas fir and western larch, with lesser amounts of Engelmann spruce, lodgepole pine, and white fir. Most of the pulp is produced in a 900 ton/day Kamyr chip digester installed in 1966. A 150 ton/day Kamyr sawdust digester was also installed at that time. Batch digesters are used to produce the pulp processed through the bleach plant. The cooking liquor used for kraft pulping in the digesters contain sulfur compounds which give rise to objectionable gaseous and particulate emissions which must be controlled to avoid degrading the quality of air.

The major potential contributor to objectionable Kraft mill emissions is the kraft recovery boiler. At Missoula, three such recovery units were operating in the late 1960's. It was recognized that in order to solve the air pollution problem at the mill, major modifications to the kraft recovery boilers, or their eventual replacement with "low emission" units, would be necessary to reduce both TRS and particulate emissions.

In 1968, a technological breakthrough of major proportions relating to the control of emissions from a kraft recovery boiler was made in the United States. In February of that year, a technical paper was given at the New York TAPPI meeting by Thoen, DeHaas, Tallent, and Davis (1) which revealed that the major source of odorous emissions (TRS) from a kraft recovery furnace was the direct contact evaporator. At that time, every kraft mill recovery furnace in the United States was equipped with a direct contact evaporator. However, both major boiler manufacturers (Babcock & Wilcox Company and Combustion Engineering) had been examining the feasibility of eliminating the conventional direct contact evaporator from their systems. Prototype units were finally developed and installed at certain mills in 1969.

In order to meet the Montana Air Emission Standards issued in late 1968, Hoerner Waldorf had to modify the recovery system at the Missoula mill in such a way that TRS emissions from the recovery boilers would not exceed 17.5 ppm (24-hour average) and particulate emissions would not exceed the guidelines developed by means of a process weight table. In the case of No. 3 recovery boiler,this table called for a maximum particulate emission level of 45.3 lb/hr. at design solids loading (100% boiler loading). Typical emissions from this boiler prior to system modifications were approximately 400 ppm of TRS and 250 lb/hr. of particulates. In essence, the best available technology was required at Missoula to meet the stringent emission standards promulgated by the State of Montana.

SECTION VI

EMISSION STUDIES AT MISSOULA BEFORE SYSTEM MODIFICATIONS

NCASI SURVEY OF TRS EMISSIONS

One of the earlier emission studies made at the Missoula mill was carried out under the direction of the West Coast Region Center of the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) during October, 1968. Some of the interesting data developed from this study pertaining to the No. 3 Recovery Boiler is tabulated in Table 1. Sulfur emission data was obtained both before (inlet) and after (outlet) the direct contact evaporator where flue gases contacted black liquor in the cyclone evaporator scrubber. Whereas the TRS level before the scrubber was below 5 ppm in all cases. the TRS level after the scrubber was in the 100-200 ppm range. This data bears out some of the earlier work reported by others in the industry (1). The detailed analysis carried out to identify specific reduced sulfur compounds indicated that at least 97% of the TRS leaving the recovery boiler was hydrogen sulfide (H_2S).

HOERNER WALDORF TRS DATA

The first Barton titrator for TRS monitoring at Missoula was purchased in 1969 and was used to check for TRS emissions from various sources in the mill. A summary of data obtained at No. 3 recovery stack during 1969-1970 is given in Table 2. The average value of this data is 391 ppm, with a range of 133-646.

INVESTIGATION OF SO_2 EMISSIONS

(Babcock and Wilcox Co. and NCASI Joint Effort)

It was recognized that the elimination of the direct contact evaporator could lead to a potential problem with the emission of sulfur dioxide (SO_2) which previously had been scrubbed out by intimate contact with alkaline black liquor in the direct contact evaporator existing in the conventional system. The first mills that started up new recovery boilers without a direct contact evaporator experienced relatively high levels of SO_2 at the stack, approaching 500-600 ppm. In order to better understand the variables affecting SO_2 emissions, a comprehensive 6-week flue gas sampling program for No. 3 recovery boiler prior to its modification was undertaken by Hoerner-Waldorf with the assistance of Babcock and Wilcox and the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI).

The testing program began the week of April 6, 1970 and involved continuous monitoring of TRS and SO_2 emissions from the recovery boiler ahead of the direct contact evaporator. Several changes were made in the operation of the boiler during this period to establish a cause and effect relationship between operating conditions and

Table 1

*NCASI DATA FOR SULFUR EMISSIONS FROM NO. 3 RECOVERY BOILER (October, 1968)

Nozzle Size/Pressure	38/32	38/32	40/32
Liquor Load (% of Rating)	100	100	110
Excess Oxygen (%)	2.2	4.0	2.5
Dry Solids (DS) Firing			
Total DS Feed(lb/hr.)	63,500	64,000	68,500
Air Demand(lb/lb DS)	4.92	5.43	5.07
Steam Generation			
Total(lb/hr.)	165,000	155,000	170,000
Total (lb/lb DS)	2.61	2.41	2.50
Sulfur Emissions (ppm)			
Hydrogen Sulfide (H_2S)			
Before DC Evaporator	0.3	2.0	4.5
After DC Evaporator	98.0	108.0	178.0
Methyl Mercaptan (CH_3SH)			
Before DC Evaporator	0.0	0.0	0.0
After DC Evaporator	3.0	6.2	2.0
Dimethyl Sulfide (CH_3SCH_3)			
Before DC Evaporator	0.0	0.0	0.2
After DC Evaporator	2.0	0.3	3.6
Dimethyl Disulfide (CH_3SSCH_3)			
Before DC Evaporator	0.0	0.0	0.0
After DC Evaporator	0.0	0.3	1.0

* Wet chemistry analytical methods used.

Table 2

*DAILY AVERAGE TRS EMISSIONS FROM NO. 3 RECOVERY SYSTEM BEFORE CONVERSION

Date	*TRS(ppm)
11/ 1/69	369
11/ 2/69	436
11/ 3/69	621
11/ 4/69	628
11/ 5/69	317
11/ 6/69	300
11/ 7/69	472
11/ 8/69	436
11/ 9/69	411
11/10/69	543
11/11/69	436
11/12/69	332
11/13/69	279
11/14/69	338
11/15/69	575
11/16/69	614
11/17/69	436
11/18/69	448
11/19/69	304
11/20/69	226
11/21/69	133
11/22/69	184
11/25/69	198
11/26/69	120
11/27/69	230
11/28/69	284
11/29/69	290
11/30/69	246
5/22/70	423
5/23/70	462
5/24/70	465
5/25/70	346
5/26/70	407
5/27/70	533
5/28/70	266
5/29/70	312
5/30/70	407
5/31/70	471
6/ 1/70	646
6/ 2/70	414
6/ 3/70	510
6/ 4/70	445
6/ 5/70	355
6/ 6/70	402
6/ 7/70	516
Average	391
Range	133-646

*Data obtained by Hoerner Waldorf personnel at Missoula using a Barton Titrator gaseous emissions. Operating variables studied were liquor sulfidity, liquor nozzle orientation, air distribution and excess oxygen.

Table 3 summarizes the data obtained from this investigation. The summary of data indicates that a major shift in SO_2 emissions occurred when the sulfidity level rose to 28%. In the 25-28% sulfidity range SO_2 values did not exceed 14 ppm. Above 28%, the average SO_2 emissions exceeded 300 ppm. This intensive study permitted Hoerner Waldorf to obtain rather tight guarantees from Babcock and Wilcox on the SO_2 emissions anticipated both from the modified No. 3 recovery boiler and the new No. 4 recovery boiler to be built in future under Phase II.

MONTANA STATE UNIVERSITY STUDIES

The No. 3 recovery boiler was used for several field trials of gaseous sulfur monitoring equipment designed in a graduate chemical engineering program at Montana State University during 1970. Table 4 is a summary of data obtained by one of the graduate students as part of his doctoral thesis. This data is supportive of emission data obtained from the other studies cited.

HOERNER WALDORF PARTICULATE EMISSION DATA

The expansion program that took place at the mill in 1966 included the installation of No. 3 recovery boiler followed by a two-stage Venturi scrubber. The first Venturi was operated on black liquor, the second on a weak caustic solution (known as "brine"). This equipment was installed by Hoerner Waldorf Corporation at a cost of $350,000 to reduce the emission of particulate matter from the mill. This system was plagued with operating problems from the outset, and only after several modifications and improvements was a collection efficiency of 96-98% obtained. The operation of such a two-stage Venturi system has been described in a technical paper by Shah and Mason (2).

Table 5 is a summary of the particulate tests run before the conversion of No. 3 recovery. These tests were all made with the boiler at or near design load for liquor solids. During 1967 and 1968 (Period 1 in Table 5) Babcock and Wilcox ran dust load tests for equipment shake-down and acceptance. Stack dust concentrations ranged from 0.19 to 0.69 grains per dry standard cubic foot (32°F, 29.92" hg) and the overall collection efficiency of the system averaged 95.6%.

Hoerner Waldorf began testing No. 3 recovery boiler in early 1969 (Period 2 in Table 5). Dust concentrations at that time ranged from 0.33 to 0.58 gr/SDCF with the collection efficiency averaging 93.6%.

Table 3

*SUMMARY OF DAILY AVERAGE TRS AND SO_2 DATA OBTAINED AT NO.3 RECOVERY BOILER EXIT

(Ahead of Black Liquor Venturi)

Date	Excess O_2(%)	Sulfidity(%)	TRS (ppm)	SO_2 (ppm)
4/12/70	0.7	34	10.8	625
4/13/70	2.5	34	18.5	615
4/14/70	3.5	34	11.7	372
4/15/70	3.5	34	0.6	236
4/16/70	2.5	34	1.9	273
4/17/70	3.5	34	2.2	441
4/18/70	3.0	34	0.8	288
4/20/70	3.5	32	0.2	354
4/24/70	2.5	28	0.1	14
4/25/70	1.5	27	0.1	4
4/26/70	1.5	26	<0.1	4
4/27/70	1.5	26	<0.1	4
4/29/70	2.1	25	<0.1	2
4/30/70	2.2	27	<0.1	<1
5/ 1/70	2.0	25	<0.1	<1
5/ 4/70	2.8	29	0.4	105
5/ 5/70	2.0	29	0.2	230
5/ 8/70	2.5	30	0.5	496
5/ 9/70	2.0	29	2.3	419
5/10/70	2.3	32	0.2	212
5/11/70	3.5	32	<0.1	420
5/12/70	3.0	31	0.4	380
5/13/70	3.8	31	11.2	502
5/14/70	3.3	32	2.6	446
5/15/70	-	32	1.3	334
5/16/70	2.0	32	3.9	194
5/17/70	3.0	32	<0.1	56
5/18/70	-	31	4.8	509
5/19/70	-	31	2.7	374

Summary of Above Data

Sulfidity Range	TRS		SO_2	
	Average	Range	Average	Range
25-28	0.03	0- 0.1	4	0- 14
29-30	0.9	0.2- 2.3	313	105-496
31-34	4.1	0-18.5	368	56-625

*Special test procedure followed in this investigation involving a 10:1 dilution of gas stream with nitrogen to avoid condensation in the sample line ahead of the Barton titrator which might affect results.

Table 4

SUMMARY OF GAS CHROMATOGRAPHY DATA COMPILED BY MONTANA STATE UNIVERSITY

		Before Venturi		After Venturi	
Date	Sulfidity (%)	H_2S(ppm)	SO_2(ppm)	H_2S(ppm)	*SO_2(ppm)
7/16/70	33.3	49	248		
7/17/70	32.5	39	372	584	0
7/18/70	34.8			225	0
7/19/70	32.8			253	0
7/20/70	32.8			210	0
7/23/70	34.2	46	294		
7/24/70	35.4	30	232		
8/ 5/70	35.2	51	449		
8/ 6/70	35.5	31	654		
8/ 7/70	35.2	65	479		
8/ 8/70	35.7	41	636		
8/10/70	35.8	13	578		
8/11/70	36.9	13	616		
8/12/70	35.5	21	648		
8/13/70	35.4	30	653		
8/17/70	36.2	13	118		
8/18/70	36.0	28	144		
8/19/70	36.5	0	228		
	Averages	31	423	318	0
	Range	0-65	118-654	210-584	-

*Detection limit estimated at 50 ppm

Table 5

PARTICULATE DATA FOR NO. 3 RECOVERY SYSTEM BEFORE CONVERSION

Period	Date	Dust Load[a] (gr/SDCF) Boiler Exit	Dust Load[a] (gr/SDCF) Stack	Scrubber Efficiency(%)	Gas Volume Flow(SDCFM)	Dust Loss at Stack(lb/hr)
1	1/ 3/67	5.0	.401	92.0		
	1/24/67	10.3	.233	97.7		
	1/25/67	8.9	.579	93.5		
		10.8	.690	93.6		
	1/26/67	7.4	.192	97.4		
		9.9	.520	94.7		
	1/27/67	6.1	.273	95.6		
		6.6	.533	91.9		
	8/ 2/67	11.4	.365	96.7		
	8/ 3/67	11.4	.514	95.4		
		11.4	.463	95.9		
	8/ 4/67	11.4	.610	94.6		
	5/14/68	7.8	.300	96.2		
		7.5	.239	97.0		
	5/15/68	9.4	.185	98.0		
		8.5	.209	97.6		
	Averages	9.0	.394	95.6		
2	3/31/69	6.76				
		8.64				
		7.19	.425		69,500	316
		7.34	.522	93.3	78,800	316
		6.32	.517		77,200	316
	4/18/69	7.25*	.439	94.0	77,100	290
			.330	95.4	76,100	215
	8/ 7/69	7.25*	.488	93.3	74,200	310
			.583	92.0	75,500	376
	Averages	7.25	.466	93.6		306
3	10/15/69	7.18	.248	96.4	85,000	180
	10/24/69	6.71	.264	96.3	99,300	220
			.286		99,000	220
	12/ 3/69	6.95**	.208	97.0	96,900	173
			.228	96.7	90,600	176
			.234	96.6	90,600	179
	12/22/69	6.95**	.237	96.6	105,100	214
			.238	96.6	99,100	203
			.241	96.5	99,100	204
	8/18/70	6.95**	.264	96.2	124,400	281
			.246	96.5	131,800	278
	Averages	6.95	.245	96.5		212

* Average from tests of March 31, 1969 used in calculations.

** Average from tests of October 15 and 24, 1969 used in calculations.

[a] Dust load at boiler exit determined by wet scrubbing train method; dust load at stack determined by alundum thimble method.

Total particulate emissions averaged 306 lbs/hr. At this time it was concluded that the predicted design efficiency of 98% could not be attained at the recommended pressure drop of 10 inches of water across each Venturi scrubber. In an effort to reduce particulate emissions, the black liquor Venturi Δ P was held near 10 inches and the "brine" Venturi Δ P raised to 20 inches. Tests in October, December, 1969, and August, 1970 (Period 3 in Table 5) indicated that the dust loss had been reduced to 212 lbs/hr. even though boiler loading had been increased somewhat.

The test method used at that time for particulate determination at the boiler exit was essentially the same wet scrubbing train method used during 1972 and 1973 for the EPA testing program which is described in Appendix C. The alundum thimble method was used for particulate sampling at the stack prior to 1972.

A summary of the various emission data collected before system modifications is given in Table 6. This is a compilation of the data presented in Tables 1 - 5 inclusive for TRS, SO_2, and particulate.

Table 6

SUMMARY OF EMISSION DATA BEFORE SYSTEM MODIFICATIONS

	Range(Average)	
	Before Venturi	After Venturi
1. Summary of TRS Emission Data		
a) NCASI Survey		
Hydrogen Sulfide(ppm)	0.3-4.5	98-178
Methyl Mercaptan(ppm)	0	2.0-6.2
Dimethyl Sulfide(ppm)	0-0.2	0.3-3.6
Dimethyl Disulfide(ppm)	0	0-1.0
b) Montana State University Data		
Hydrogen Sulfide(ppm)for 33-37% Sulfidity Range	0-65(31)	210-584(318)
c) Babcock & Wilcox Investigation		
TRS(ppm)for 25-28% Sulfidity Range	0-0.1(0.03)	
TRS(ppm)for 29-30% Sulfidity Range	0.2-2.3(0.9)	
TRS(ppm)for 31-34% Sulfidity Range	0-18.5(4.1)	
d) Hoerner Waldorf Daily Average Data		
TRS(ppm)		133-646(391)
2. Summary of SO_2 Emission Data		
a) Babcock & Wilcox Investigation		
SO_2 Emissions(ppm)for 25-28% Sulfidity Range	0- 14(4)	
SO_2 Emissions(ppm)for 29-30% Sulfidity Range	105-496(313)	
SO_2 Emissions(ppm)for 31-34% Sulfidity Range	56-625(368)	
b) Montana State University Data		
SO_2 Emissions(ppm)for 32-37% Sulfidity Range	118-654(423)	< 50
3. Summary of Particulate Emission Data		
a) Hoerner Waldorf Stack Emission Data(lb/hr.)		173-281(212)

SECTION VII

PRELIMINARY ENGINEERING STUDIES

The issuance of Montana Air Emission Standards late in 1968 provided Hoerner Waldorf with firm guidelines for the successful completion of ongoing engineering studies required to arrive at a satisfactory solution to the air pollution problem at Missoula. The state standards applied to both particulate emissions and total reduced sulfur gas emissions (TRS) from kraft recovery boilers. The standard for TRS emissions went into effect on November 30, 1972 and specified a maximum allowable emission limit of 17.5 ppm based on a 24-hour average. The particulate emission standard for existing boiler units went into effect on June 1, 1970. It was based on a process weight table that called for a maximum particulate emission from No. 3 recovery boiler of 45.3 lb/hr. at design solids loading (100% boiler loading).

Since it was impossible to bring the mill into full compliance with the promulgated emission standards by the effective dates specified, a variance was requested by the mill which was granted. This enabled the mill to continue to operate until corrective measures could be implemented.

On December 9, 1968,a $4,000 contract was entered into by Hoerner Waldorf and Babcock and Wilcox which called for the latter to undertake certain engineering studies to evaluate, propose, and design systems for the effective control of odorous gases, particulate matter and water vapor from the recovery units at Missoula.

Exhaustive engineering and economic studies were undertaken to determine the best overall solution to the air pollution problem, taking into consideration results anticipated (reduction in emissions), capital investment, and operating cost. Two basic concepts were considered and studied in detail by developing seven possible alternate plans that would result in mill compliance with the Montana State regulations. The basic concepts considered were:

1. Modify existing equipment only.
2. A combination of modifying some or all of the existing equipment and the addition of new recovery capacity.

The seven options considered were the following:

1. Add electrostatic precipitators to the three existing recovery boilers to effectively reduce particulate emissions. The precipitators would be installed after the direct contact evaporators and no reduction in TRS would result.
2. Install a "hot" precipitator between the recovery boiler economizer outlet and the direct contact evaporator. Odor control would be accomplished by providing adequate black liquor oxidation facilities.

3. Similar to Option 2, except that the precipitator would be installed after the direct contact evaporator. Some removal of economizer surface would be necessary to raise the temperature of flue gas entering precipitators to protect them against corrosion.

4. Conversion of existing system to the new "controlled odor" concept. This would involve the installation of a precipitator; the elimination of direct contact evaporators; the installation of additional economizer surfaces to all three recovery units to absorb the additional heat available in the flue gases; the installation of a heavy black liquor concentrator.

5. Similar to Option 4 except no economizer changes would be made to the two smaller recovery units (No. 1 and No. 2). A higher flue gas temperature leaving the boilers would result.

6. Conversion of No. 3 recovery to a "controlled odor" unit. Replacement of No. 1 and No. 2 recoveries with a new and larger recovery having adequate capacity to insure full mill production.

7. Conversion of all three existing recovery boilers to the "controlled odor" mode. Installation of a fourth, relatively small new recovery boiler to provide the necessary burning capacity to balance total recovery capacity with full mill production capacity.

To insure minimum TRS emissions from a recovery boiler it is necessary to operate the unit at rated capacity with adequate air and turbulence in the upper oxidation zone of the furnace. This means that the recovery furnace then becomes a capacity-sensitive unit and determines to a large extent the production capacity of the entire mill. This capacity is the pulp tonnage that generates the total quantity of black liquor solids (B.L.S.) that the recovery units can burn under design load conditions (100% rated loading).

In the last two options considered for recovery system modifications, additional capacity was provided to insure full mill production.

Table 7 is a summary of all pertinent cost data developed in 1969 by the initial engineering studies made in 1969. The "one time" capital investments or outage expenses were converted to an equivalent annual cost based on a 15% capital recovery factor (before taxes). Taking all factors into consideration, it was determined that options six and seven were the only acceptable solutions that would control both TRS and particulate emissions at the most reasonable cost.

Table 7

SUMMARY OF COSTS FOR SEVEN MODIFICATION PLANS CONSIDERED IN 1969

PLAN NO.	1	2	3	4	5	6	7
(A) Total Capital	$3,980,000	$5,300,000	$4,410,000	$6,850,000	$5,060,000	$9,350,000	$10,020,000
(B) Cost of Outage	$ 210,000	$ 840,000	$ 210,000	$1,566,000	$ 246,000	$ 0	$ 0
(C) Total "One Time" Cost (A + B)	$4,190,000	$6,140,000	$4,620,000	$8,416,000	$5,306,000	$9,350,000	$10,020,000
(D) Annualized Cost of (C)	$ 775,000	$1,069,000	$ 844,000	$1,432,000	$ 950,000	$1,513,000	$ 1,645,000
CONTINUING ANNUAL EXPENSES - ( ) Indicates Savings							
(E) Lower Production	$ 0	$2,760,000	$2,760,000	$2,760,000	$2,760,000	$ 0	$ 0
(F) Operating Savings	$ (140,000)	$ (203,000)	$ (97,000)	$ (297,000)	$ (223,000)	$ (443,000)	$ (263,000)
(G) Property Taxes & Insurance	$ 25,000	$ 34,000	$ 28,000	$ 45,000	$ 33,000	$ 65,000	$ 70,000
(H) Total Annual Expense (E + F + G)	$ (115,000)	$2,591,000	$2,691,000	$2,508,000	$2,570,000	$ (378,000)	$ (193,000)
(I) Net Annual Increased Costs (D + H)	$ 660,000	$3,660,000	$3,535,000	$3,940,000	$3,520,000	$1,135,000	$ 1,452,000
True (After Tax) Rate of Return	4-1/2%	NONE	NONE	NONE	NONE	NONE	NONE

It was finally decided to replace the two smaller recoveries (No. 1 and No. 2) with a larger, new unit to be designated as No. 4 recovery boiler. The No. 3 recovery unit would be modified according to the "controlled odor" design system proposed by Babcock and Wilcox. The conversion of the two smaller recoveries was not attractive because of the lengthly outage time required for their conversion, resulting in unacceptable lost production in the mill. The implementation of major modification work to them would have been more difficult, also, due to their relative inaccessibility.

The final plan, agreed to on July 23, 1969 at a meeting with Babcock and Wilcox, consisted of two parts: Phase I would be the conversion of No. 3 recovery boiler to a low-emission unit; Phase II would be the construction of a large, new low-emission recovery boiler to replace the two older, smaller recoveries.

SECTION VIII

PROPOSED SOLUTION

The final pollution abatement plan submitted to the Montana State Board of Health designated as Phase I for the conversion of No. 3 recovery boiler was intended to correct the total emission problem - particulate emissions, odorous gases, and water vapor. The results anticipated were: particulate emissions not to exceed 45.3 lb/hr. at design boiler load; TRS emissions not to exceed 17.5 ppm (24 hour average); approximately a 40% reduction in water vapor to essentially eliminate plume visibility.

Phase I consisted primarily of converting the No. 3 recovery boiler from a conventional kraft unit to a "controlled odor" design unit by the elimination of the direct contact evaporator, the major source of reduced sulfur gas (TRS) emissions. The solids content of black liquor would be raised from 40% to 63% by means of a heavy liquor concentrator (forced circulation evaporator) before being fed to the recovery furnace. A high efficiency electrostatic precipitator (99.125%) with a dry bottom would collect the particulate from the flue gases and return it to process. An additional vertical steel tube water economizer would increase the feedwater temperature to the boiler by recovering flue gas heat previously used for direct contact evaporation. At the same time, the temperature of boiler exit gases would be reduced prior to their entry into the precipitator, thereby reducing the total volume of gases discharged. A new induced draft (I.D.) fan would also be installed on the discharge side of the precipitator thereby making it a "clean" unit.

The total conversion job under Phase I was to cost approximately $2,600,000 and take 18 months to complete. The State of Montana issued Construction Permit No. 100-0311-70 on December 15, 1969 for the conversion of the No. 3 recovery system.

Figure 2 is a flow diagram showing the new modified system, complete with concentrator, precipitator, and economizer addition. Figure 3 indicates the before and after arrangement of ductwork and scrubbers.

With the elimination of the direct contact evaporator additional supplemental evaporation had to be provided to raise the black liquor concentration above the 60 percent solids level necessary for good combustion. The Unitech concentrator selected for this purpose had an evaporation capacity of 49,000 lb of water per hour provided by 10,000 square feet of heating surface. This concentrator is a long tube, forced-circulation evaporator with preheat, falling film and rising film sections. Steam (50#) is used on the shell side to provide the necessary heat for evaporation.

The No. 3 recovery boiler was installed by Babcock and Wilcox in 1966. It has a design load rating of 1,400,000 lb/day of dry solids based on 6600 BTU/lb dry solids (D.S.). This is equivalent to a nominal

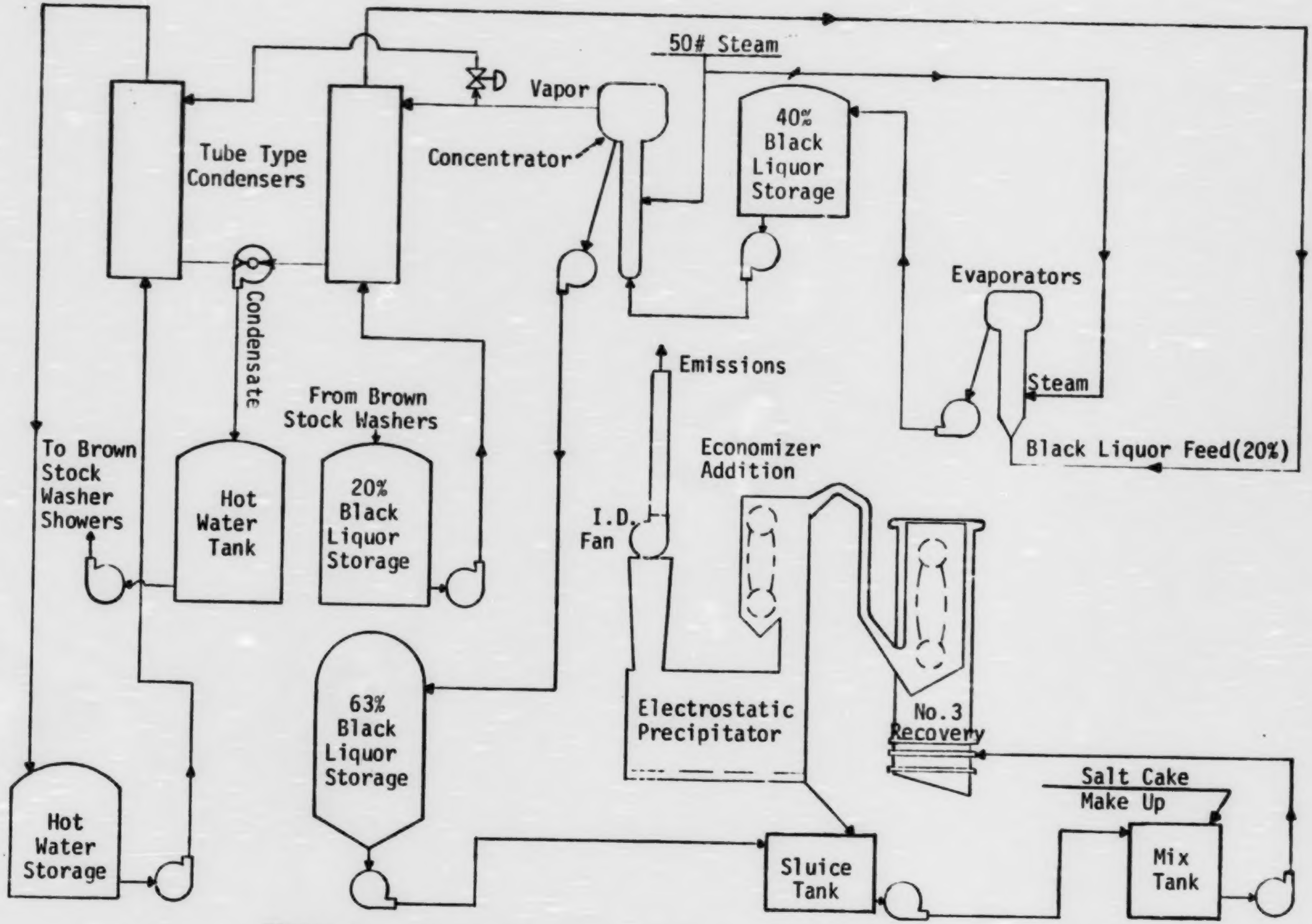

Tube Type
Condensers
Concentrator
Vapor
50# Steam
40%
Black
Liquor
Storage
Evaporators
Steam
Black Liquor Feed(20%)
Condensate
From Brown
Stock Washers
Emissions
Economizer
Addition
To Brown
Stock
Washer
Showers
Hot
Water
Tank
20%
Black
Liquor
Storage
I.D.
Fan
63%
Black
Liquor
Storage
Electrostatic
Precipitator
No.3
Recovery
Salt Cake
Make Up
Hot
Water
Storage
Sluice
Tank
Mix
Tank

Figure 2 Flow diagram for No. 3 recovery system

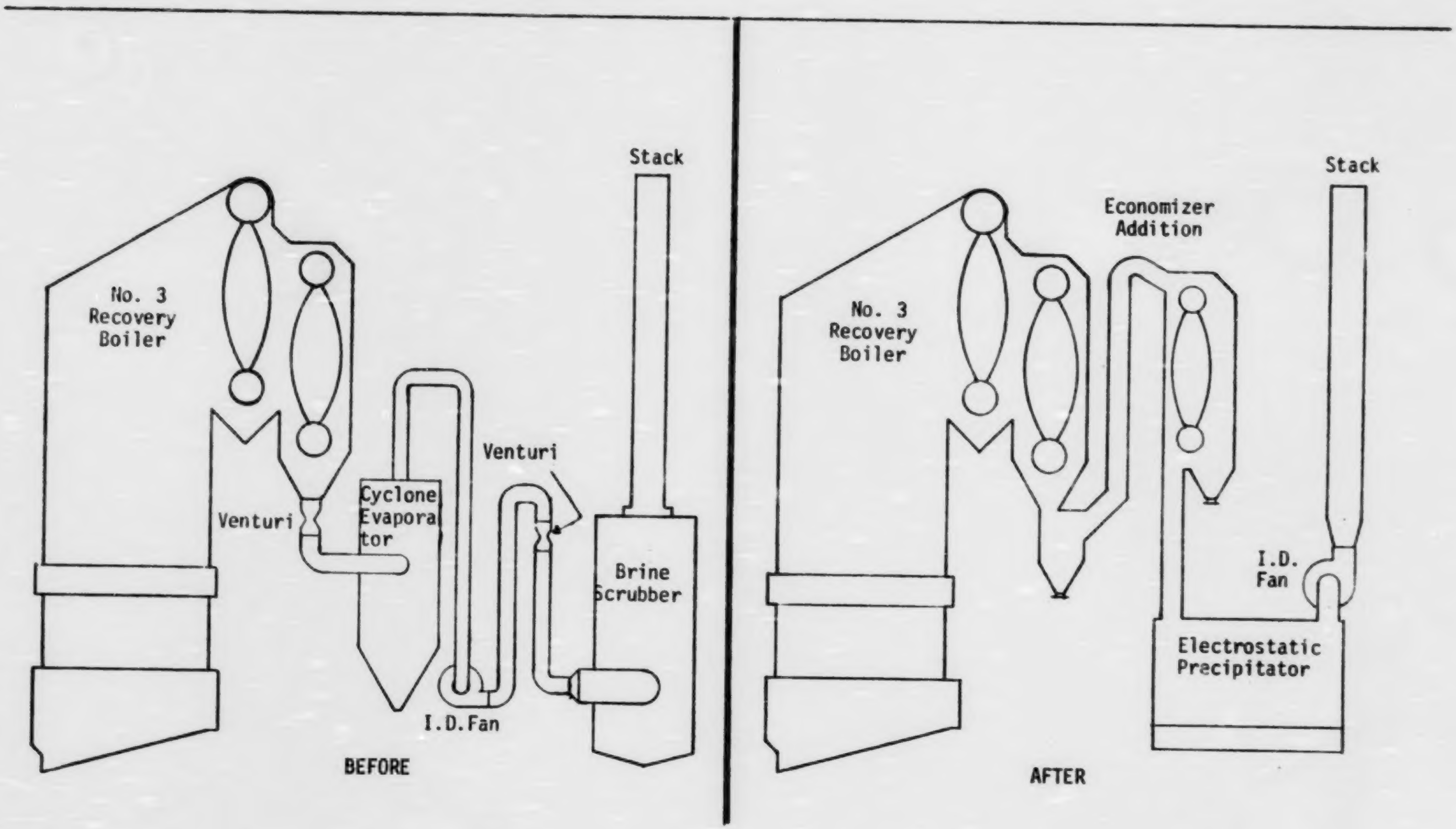

No. 3
Recovery
Boiler
Venturi
Cyclone
Evaporator
I.D.Fan
Venturi
Stack
Brine
Scrubber
BEFORE
No. 3
Recovery
Boiler
Economizer
Addition
Stack
I.D.
Fan
Electrostatic
Precipitator
AFTER

Figure 3 Conversion of No. 3 recovery system

capacity of 470 tons per day of pulp processing capacity (based on 3000 lb D.S./pulp ton). Steam capacity of the boiler is 235,000 lb/hr. at 750°F and 600 psi. Although no basic physical changes were made to the boiler, proper operation of the unit is essential to insure that the overall system functions properly to insure minimum emissions. Under design load conditions the dust concentration (particulates) in the boiler exit gases should not exceed 8.0 grains/SDCF (equivalent to 5520 lbs/hr.).

The hot gases leaving the boiler pass through the new duct work leading to the inlet of the No. 2 economizer. Additional heat is reclaimed by the boiler feedwater passing through the economizer tubes where the flue gas temperature is reduced from 600-650°F to 400°F.

The dust-laden gas then enters the electrostatic precipitator. The precipitator has two parallel chambers with three electrical sections (fields) in each. The cross section of each chamber is divided into 27 gas passages by the collecting electrode plates. The dust particles, electrically charged in the corona of the discharge wires, are attracted to the ground plates, and adhere to the plates as they lose their charge. Periodically the plates and wire frames are vibrated or "rapped" to dislodge the adhering salt cake. The dislodged dust falls to the bottom of the precipitator and is dragged to the front where it falls into a screw conveyor and is finally discharged into the sluice tank. Heavy duty drag chains, two per chamber and parallel to gas flow, are used in the dust removal system.

The design gas flow specified for the unit is 207,000 ACFM at a temperature of 400°F. The precipitator has a guaranteed collection efficiency of 99.125% (by weight) based on a dust load of 8.0 grains/SDCF in the entering gas stream for 100% boiler loading. Dust load at the precipitator outlet would then be 0.07 grains/SDCF, equivalent to 45 lb/hr.

The design details for the major components of the modified recovery system described above are given in Appendix A.

SECTION IX

PLAN IMPLEMENTATION

The original timetable for engineering and construction of Phase I is indicated in Figure 4 by means of a CPM diagram. Once the decision was made to split out the No. 3 recovery conversion project and proceed with it independently, the rest of the planning proceeded quite rapidly. The Grover Dimond Engineering Company of St. Paul, Minnesota was hired to coordinate the overall project. This involved working directly with the Engineering Department of Hoerner Waldorf, the personnel at the Missoula mill and the various contractors hired to do the actual construction work. Bids were let and contracts awarded during March, 1970 according to schedule. Steel fabrication proceeded on schedule and steel erection took place during the period August through November, 1970.

The first major component of the new system to be completed was the concentrator which had its shakedown in March, 1971. The erection of the precipitator was completed in mid-April. No. 3 recovery was then shut down April 19 to the 27 to permit installation of the transition piece of duct work between the existing boiler and the new economizer. The modified recovery system started up on April 28, 1971.

Additional accomplishments within the scope of Phase I were: the conversion of one of the former cyclone separators to a storage tank for 63% solids black liquor; the installation of a dry salt cake handling system to take the place of the former water slurry system; the installation of a new I.D. fan at the precipitator outlet.

The capital cost breakdown for the modifications made to the No. 3 recovery system is given in Table 8.

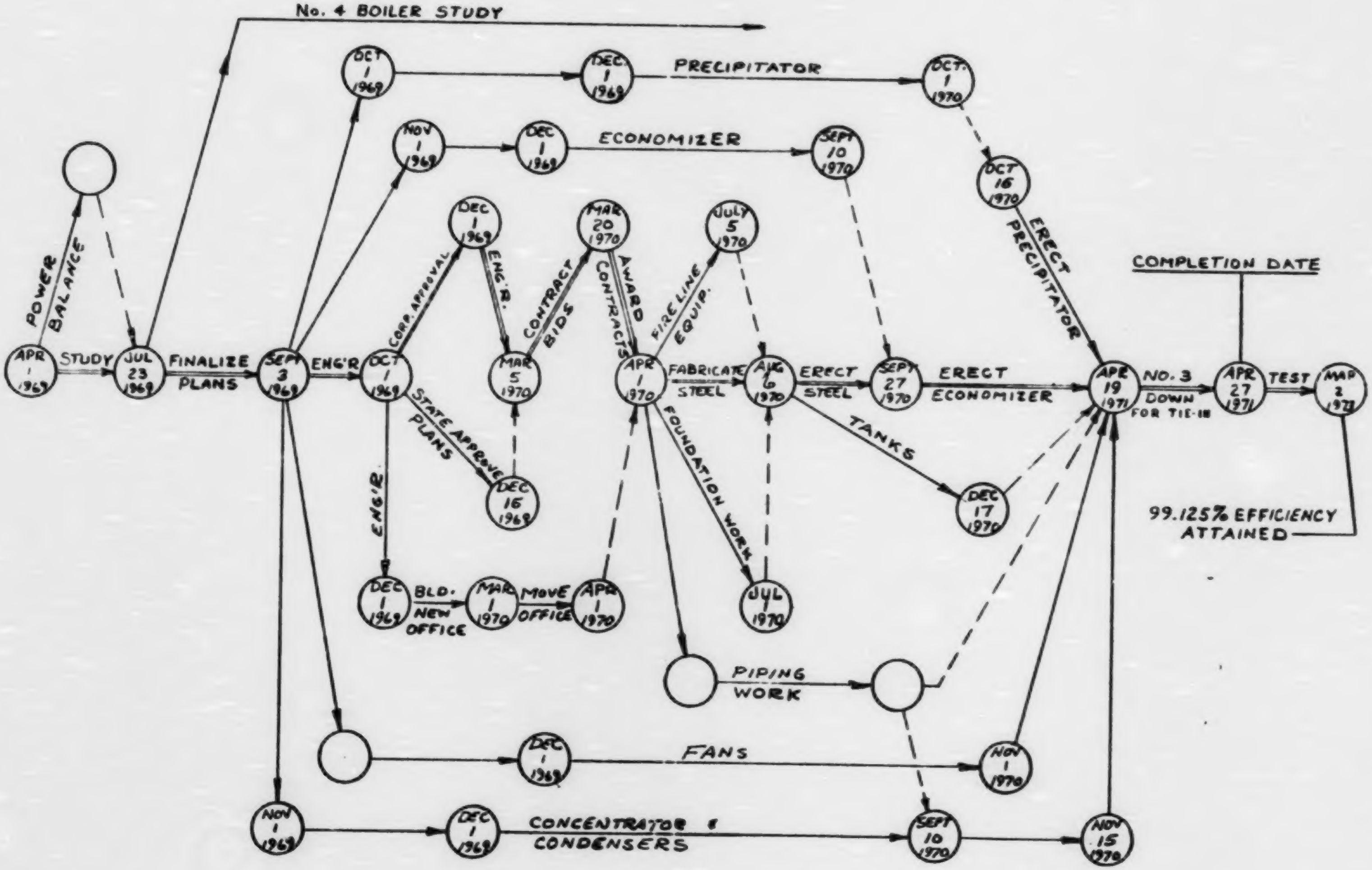

No. 4 BOILER STUDY
POWER BALANCE
STUDY
APR 1 1969
JUL 23 1969
FINALIZE PLANS
SEPT 3 1969
ENG'R
OCT 1 1969
DEC 1 1969
PRECIPITATOR
OCT. 1 1970
OCT 16 1970
ERECT PRECIPITATOR
NOV 1 1969
DEC 1 1969
ECONOMIZER
SEPT 10 1970
CORP. APPROVAL
DEC 1 1969
ENG'R.
MAR 5 1970
STATE APPROVE PLANS
DEC 16 1969
CONTRACT BIDS
MAR 20 1970
AWARD CONTRACTS
APR 1 1970
FIRE LINE EQUIP.
JULY 5 1970
FABRICATE STEEL
AUG 6 1970
ERECT STEEL
SEPT 27 1970
ERECT ECONOMIZER
TANKS
DEC 17 1970
FOUNDATION WORK
JUL 1 1970
ENG'R.
DEC 1 1969
BLD. NEW OFFICE
MAR 1 1970
MOVE OFFICE
APR 1 1970
PIPING WORK
FANS
DEC 1 1969
NOV 1 1970
NOV 1 1969
DEC 1 1969
CONCENTRATOR & CONDENSERS
SEPT 10 1970
NOV 15 1970
APR 19 1971
NO. 3 DOWN FOR TIE-IN
APR 27 1971
TEST
MAR 2 1971
COMPLETION DATE
99.125% EFFICIENCY ATTAINED

Figure 4 CPM diagram for No. 3 recovery system modifications

Table 8

*CAPITAL COST SUMMARY FOR NO. 3 RECOVERY MODIFICATIONS
(Hoerner Waldorf Project 70-701)

Building		$ 851,767
No. 2 Economizer		365,739
Concentrator		140,688
Electrostatic Precipitator		389,490
Auxiliary Equipment		90,226
I.D. Fan	$27,226	
I.D. Fan Turbine	29,457	
Salt Cake Feed System	24,674	
Sluice Tank & Agitator	8,869	
Miscellaneous		102,128
Duct Work Cutover From Boiler to No.2 Economizer	$59,444	
Conversion of Cyclone Evaporator to Liquor Storage Tank	6,050	
Other	36,634	
Piping and Valves		250,718
Electrical Work		183,641
Instrumentation Work		67,850
Overhead		47,121
Architecture and Engineering Service		109,734
	Total	$2,599,102

* Detailed Design and Engineering Data are given in APPENDIX A

SECTION X

SYSTEM SHAKE-DOWN

The modified No. 3 recovery system began operation on April 28, 1971. Particulate collection and removal was the one area of operation that did not function properly initially and required considerable modification over a period of many months before collection efficiencies approaching 99% were reached.

The early operation of the electrostatic precipitator was hampered by the inability of the screw conveyor to carry away the salt cake from the hoppers located beneath the precipitator. The trough in which the screw conveyor was located would bridge over on one or both sides. If just one side plugged, the precipitator compartment was isolated with dampers and gates, and the salt cake washed out. If both sides plugged, an outage was required. Early attempts at preventing this plugging included the installation of chains over the screw conveyor, mounting of vibrators on the outside of the trough, and speeding up the screw conveyor. None of these changes alleviated the problem. The conveying problem was finally solved by changing the angle at which the salt cake discharged into the trough and by installing a new set of screws with larger flights (9" flights at 9" pitch replaced with 12" flights at 12" pitch).

Essentially all of the problems with the particulate handling system resulted from improper engineering of the system based on an assumed bulk density figure for particulate considerably higher than that later experienced.

After solving the conveying problem at the precipitator, the operability of the rest of the equipment was investigated. The Unitech concentrator performed well from the very start. Product solids have been as high as 66%, but normal operation calls for 63% solids. The concentrator is boiled out once per day with weak black liquor (20% solids) to prevent solids buildup or tube plug up.

Gradual pluggage in the No. 2 economizer by dust carryover in the flue gases resulted in operating problems. This pluggage increased the pressure drop across the unit to the point where the induced draft (I.D.) fan did not have adequate capacity to maintain satisfactory excess oxygen (2-3%) at the boiler exit required to minimize TRS emissions. To correct the problem, it was necessary to shut the boiler down twice each month in order to water wash or hand lance with steam the internals of the economizer. Finally, in February 1972 two additional sootblowers were installed, one at the inlet and the other near the outlet to minimize the pluggage problem (see Figure 5). This modification was successful. During the next 15 months, the No. 2 economizer required cleaning on only five occasions. In May, 1973 three stationary sootblowers were installed on the outlet of the No. 2 economizer. Since then plugging problems have been virtually eliminated. There has been only one cleaning since that time.

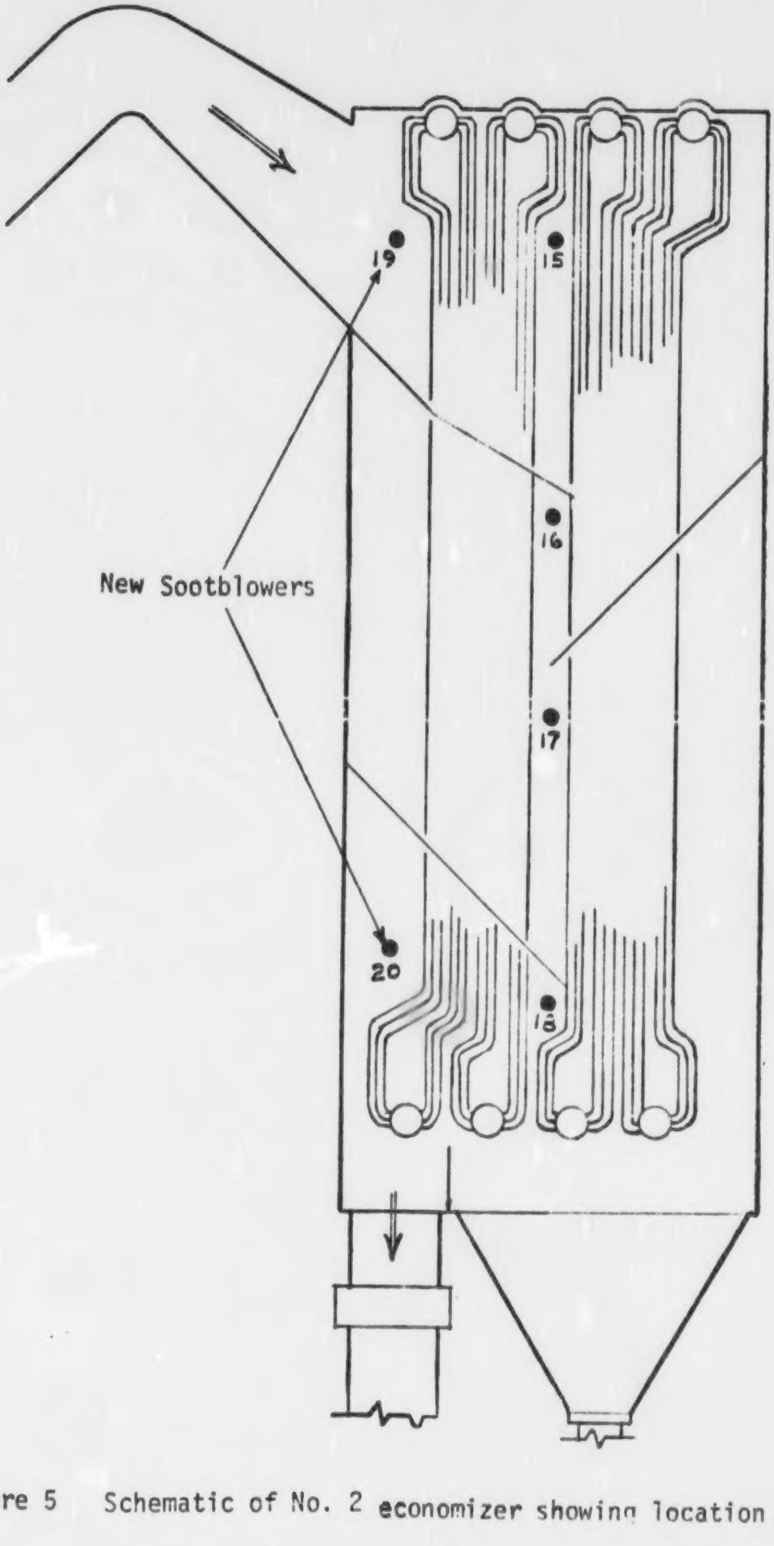

19
15
16
New Sootblowers
17
20
18

Figure 5 Schematic of No. 2 economizer showing location of I K sootblowers

Repeated tube leakage at the weld points was a second troublesome problem encountered with the No. 2 economizer. This occurred despite an x-ray program for inspection of field welding carried on at the time of construction. Over a 2-year period, some 35 leaks were discovered and repaired at a total cost of $16,000.

Following the completion of modifications made to the No. 3 recovery system, extensive testing of exit gases from both the recovery boiler and the precipitator was carried out to establish the dust collection efficiency of the latter. Boiler operation and emission test data were taken on almost a daily basis.

The first two months following the April 28, 1971 startup were devoted almost entirely to balancing furnace conditions in order to reduce dust concentration in the boiler exit gases from 9.40 to 8.0 grains/SDCF. The latter figure was the anticipated or vendor-predicated boiler emission at design load and was one of the basic design parameters for the new precipitator. Burner nozzle size, nozzle pressure, and air distribution to the furnace were all varied in an effort to reduce this boiler exit dust load.

Table 9 summarizes the results obtained from this effort. It was finally possible in July, 1971 to establish an acceptable dust load (8.0 grains/SDCF) leaving the boiler under full (design) load conditions.

The collection efficiency of the precipitator remained at 94%-95% even after the above adjustments in boiler operation had been made. This data is summarized in Table 10 under Period 1. The precipitator manufacturer felt that poor gas distribution was the problem and recommended that the inlet turning vanes be modified by installing vertical extensions on the first four steps of the ladder. This was done during the July 4 shutdown period, but no measureable improvement in operations resulted.

Research-Cottrell continued to suspect poor gas distribution and ran a hot-wire anemometer test during the Labor Day shutdown. This test indicated that some of the untreated gases were sweeping across the bottom of the precipitator. For the next several months, several electrical as well as physical modifications were made to the precipitator, first to the north side for initial evaluation and then to the south side if they proved to have merit. These changes included the following, some of which are illustrated in Figure 6.

1. Vertical extensions were added to the inlet turning vanes of the north compartment, four on July 4, 1971, and an additional 15 on November 10, 1971. This modification made little or no difference in the precipitator operation and was not repeated in the south compartment. These were later removed from the north chamber in February, 1972.

Table 9

NO.3 RECOVERY FURNACE DATA FOR SHAKE-DOWN PERIOD (1971)
(Boiler Operating Conditions vs. Boiler Exit Dust Load)

	Air Flows (M lb/hr.)				Nozzle			
Period	Primary	Secondary	Tertiary	Total	Size	Pressure (psig)	Boiler Exit Dust Load (Grains/SDCF)	No.2 Economizer Exit Gas Volume (ACFM)
5/18 - 6/2/71	194	116	57	367	38	35	9.40	200,600
	(53%)	(32%)	(15%)					
6/3 - 6/10/71	174	139	60	373	38	34	9.31	197,900
	(47%)	(37%)	(16%)					
7/20 - 8/11/71	181	131	60	372	38	30	8.10	197,400
	(49%)	(35%)	(16%)					

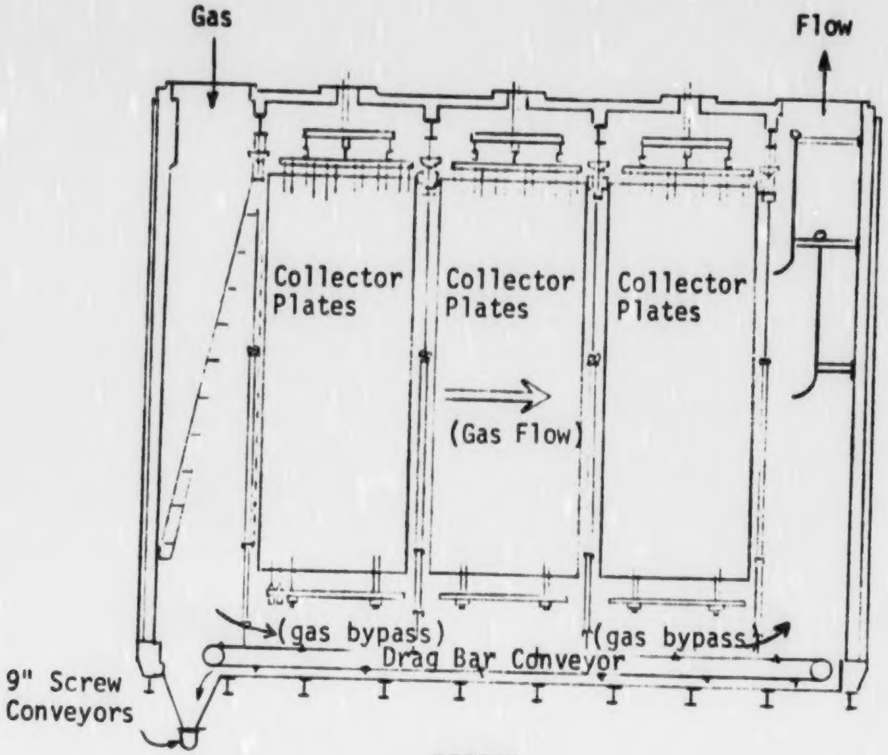
Table 10

*PARTICULATE EMISSIONS FROM NO. 3 PRECIPITATOR AFTER CONVERSION

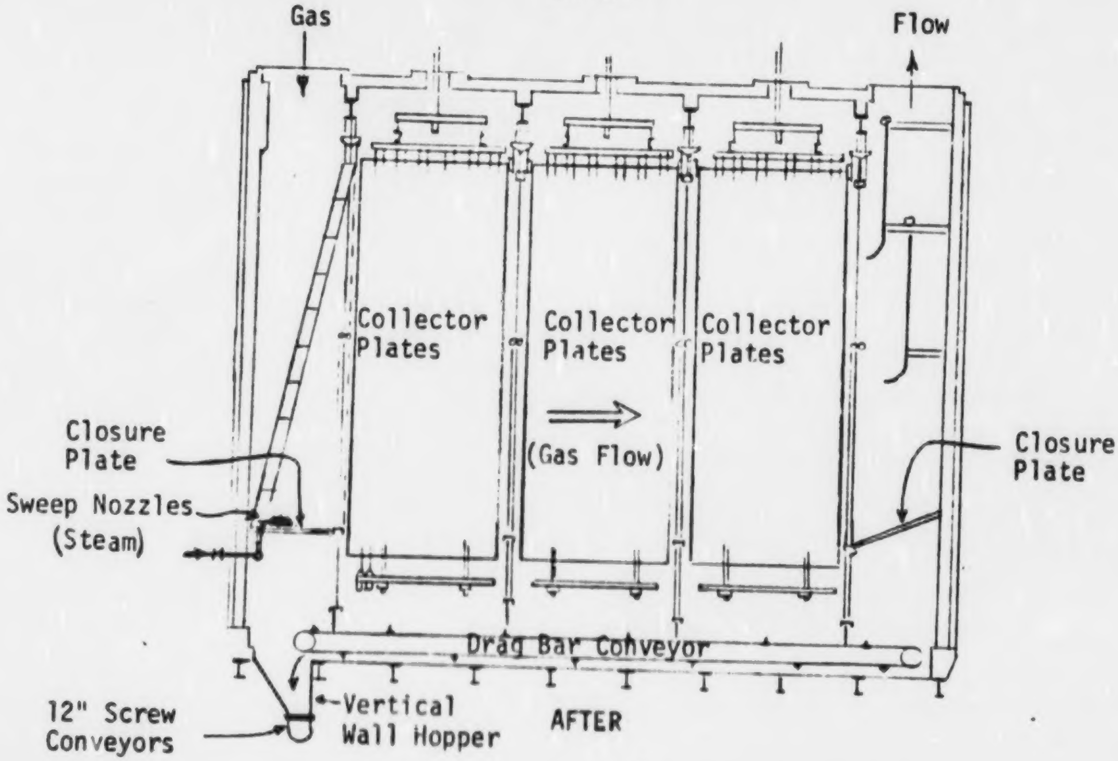
Period 1		2		3		4	
Date	Lb/Hr.	Date	Lb/Hr.	Date	Lb/Hr.	Date	Lb/Hr.
6/15/71	225	1/28/72	160	6/14/72	71	1/ 8/73	38
6/19/71	263	1/29/72	197	6/16/72	59	1/11/73	55
6/21/71	243	2/ 1/72	108	6/17/72	59	1/11/73	45
6/22/71	231	2/ 2/72	128	6/17/72	60	1/15/73	45
6/24/71	226	2/ 8/72	118	6/22/72	69	1/17/73	46
6/25/71	251	2/ 9/72	83	6/22/72	59	1/18/73	38
6/28/71	268	2/11/72	137	6/27/72	85	1/19/73	56
7/10/71	221	2/16/72	113	7/13/72	92	1/31/73	65
7/12/71	226	2/28/72	80	7/14/72	90	2/ 5/73	29
7/13/71	258	3/ 1/72	84	7/14/72	86	2/ 7/73	25
7/14/71	298	3/ 3/72	116	7/19/72	84	2/12/73	61
7/15/71	206	3/13/72	142	8/ 2/72	75	2/13/73	58
7/20/71	236	3/16/72	53	8/10/72	63	3/ 1/73	58
7/21/71	259	4/27/72	107	8/11/72	74	3/ 1/73	52
7/22/71	255	6/ 2/72	99	8/11/72	66	3/ 2/73	41
7/23/71	253			8/17/72	59	8/22/73	44
7/26/71	286			10/ 4/72	113	8/30/73	37
7/27/71	267			10/ 9/72	76	8/31/73	24
7/29/71	268			10/12/72	57	12/12/73	29
7/30/71	262			10/13/72	73	12/13/73	21
8/ 1/71	264					12/14/73	22
8/ 4/71	279						
9/ 8/71	166						
9/14/71	213						
9/15/71	195						
9/16/71	207						
9/20/71	224						
9/28/71	224						
11/18/71	376						
11/22/71	372						
12/18/71	279						
1/19/72	240						
Averages	251		115		73.5		42.3
**Efficiency(%)	95.5		97.9		98.7		99.2

*Hoerner Waldorf Test data based on Alundum Thimble Method of collection

**Based on incoming design dust load of 8 grains/SDCF (5520 lb/hr.)


Gas
Flow
Collector Plates
Collector Plates
Collector Plates
(Gas Flow)
(gas bypass)
(gas bypass)
Drag Bar Conveyor
9" Screw Conveyors

BEFORE


Gas
Flow
Collector Plates
Collector Plates
Collector Plates
(Gas Flow)
Closure Plate
Sweep Nozzles (Steam)
Closure Plate
Drag Bar Conveyor
12" Screw Conveyors
Vertical Wall Hopper

AFTER

Figure 6 Precipitator modifications

2. A horizontal closure plate was installed at the bottom of the turning vanes at the precipitator inlet to prevent the flow of gases around the drag conveyor, thus bypassing the inlet collecting plates. This was done on November 10, 1971.

3. Replacement of the P-150 Eriez rappers (rated at 110G) on all high tension wire frames and on the inlet section plate rappers with P-160 Eriez rappers (rated at 300G). Some were changed out on November 10, 1971 and the remainder on January 7, 1972.

4. On January 11, 1972 a closure plate was installed on the north side outlet to reduce the possibility of gases bypassing the outlet plates. Also at this time, skirting was replaced again in the center section baffle above the drag conveyor.

Precipitator efficiency tests run on the north side the week after these last physical changes were made in January, indicated a significant improvement in efficiency (from 93.5% to better than 98.5%). As a result, similar changes were made to the south compartment later in the month. Also, the unbalanced gas flow between the two compartments was corrected by the installation of a gas splitter in the "pants legs" of the inlet ducting on February 16, 1972. By balancing the gas flows an overall collection efficiency of 97.5 - 98-0% was obtained as indicated by the particulate data tabulated in Table 10 for Period 2.

Additional electrical modifications were made to the precipitator in June, 1972 in an effort to reach the guaranteed efficiency of 99.125%. This involved sectionalization of electric input to obtain better and more positive control of each electrical section. A 1500ma transformer-rectifier set was installed to power the center field. The existing 1000ma center field set was reconnected to the outlet field, providing it with two transformer-rectifier sets of equal power. Another modification made was the installation of horizontal rappers to keep the gas inlet distribution plates clean. These modifications raised the collection efficiency to a level of 98.5-99.0% as indicated for Period 3 in Table 10.

During the 1972 Christmas shutdown, a number of additional mechanical modifications were made to the precipitator upon the recommendation of Research-Cottrell in an effort to further reduce any bypassing of flue gases through the chambers, to minimize unwanted draft effects, and to improve the cleanliness of the high tension wires. The corrective measures carried out were the following:

1. Vertical seal strips were installed between the end collecting plates and the tile walls, (first and last fields).

2. Seal plates were installed between the top plate perimeter and the tile walls.

3. Baffle plates were installed between the bottom plate perimeter and the tile walls.

4. Baffle plates were installed in the top outlet field to the structural cross beam.

5. The outlet flue baffle plate was sealed to tile wall.

6. The stiff electrodes were removed from high tension frames and replaced with wire hangers.

7. Teflon stabilizer bars were installed at the bottom of the high tension frames.

Additional final "tuning" carried out under the direction of Research-Cottrell enabled the precipitator to finally reach its design collection efficiency of 99.125%, some 22 months after the unit was first put into operation. This final data is summarized under Period 4 in Table 10.

Particulate emissions from No. 3 recovery boiler were then able to meet the requirements called for in the process weight table incorporated in the Montana Air Emission Standards. This was a maximum emission of 45.3 lb/hr., equivalent to a discharge grain loading of 0.07 grains/SDCF. The precipitator successfully met its acceptance test on March 2, 1973. The intensive EPA test program for No. 3 recovery boiler began on March 5.

SECTION XI

GENERAL EVALUATION OF THE MODIFIED RECOVERY SYSTEM

BLACK LIQUOR FEED SYSTEM

Fluctuations in black liquor solids have decreased significantly since the conversion of the system to a "controlled odor" design. The major design change was the elimination of all direct contact between the black liquor and flue gas. Solids are now concentrated in a separate indirect contact evaporator known as a concentrator. From the concentrator, liquor of 63% solids is pumped to an intermediate storage tank converted from the cyclone evaporator used in the earlier system. From here, the liquor is pumped to the sluice tank located beneath the precipitator where particulate dust is reclaimed. The liquor is pumped from the sluice tank to the mix tank where fresh salt cake is added to the liquor to make up chemical losses incurred in the pulping operation. The fresh salt cake addition raises the solids level in the black liquor approximately one percent. The mixed liquor is finally pumped to the single oscillating spray nozzle located at the front of No. 3 recovery furnace.

SALT CAKE FEED SYSTEM

In the old system, salt cake was made up as a water slurry before being fed to the recovery system. This common feed system, feeding all three recovery boilers, was plagued by periodic plugging and frequent mechanical breakdown. The newly installed system handles only that quantity of salt cake required for makeup in the No. 3 recovery system. A calibrated screw conveyor provides relatively good control of the feed rate for the dry makeup chemical.

STEAM PRODUCTION

Prior to the conversion, solids in the liquor feed to the burner nozzle averaged 1.59 million pounds per day and steam production averaged 4.42 million pounds per day, equivalent to 2.78 pounds of steam per pound of solids. After the conversion, the solids feed at the nozzle averaged 1.48 million pounds per day at a somewhat lower boiler loading and steam production averaged 5.37 million pounds per day, equivalent to 3.62 pounds steam per pound of solids. The greater steam produced is the result of extracting additional heat from the flue gas as it passes through the second economizer. This heat previously had been used for direct contact evaporation in the venturies. However, in the new system, additional steam is required to raise the black liquor solids from 40 percent to 63 percent in the concentrator. The net available steam for other mill processes is 2.83 pounds per pound of solids or essentially the same quantity as that available from the previous system. Table 11 summarizes this steam data.

Table 11

SOLIDS THROUGHPUT AND STEAM PRODUCTION FOR NO. 3 RECOVERY BOILER
(All Figures Expressed in 1000 lbs/day)

Period	Year	Solids Feed at Nozzle	Steam Production	Steam to Concentrator	Useable Steam To Process
1-Before Modification					
	1968	1530	4215	0	4215
	1969	1602	4435	0	4435
	1970	1636	4616	0	4616
Average		1589	4422	0	4422
Steam/Solids Ratio			-2.78-		-2.78-
2-After Modifications					
	1971	1516	5295	1111	4184
	1972	1452	5454	1246	4208
Average		1484	5374	1178	4196
Steam/Solids Patio			-3.62-		-2.83-

INDUCED DRAFT (I. D.) FAN

In the previous system, stack gases were under a positive pressure between the induced draft fan and the stack. Between the fan and the brine venturi the pressure was about 22 inches of water. All system leaks made conditions uncomfortable for the operators working in the area since flue gases were being discharged into the building. Because the new fan is on the discharge side of the precipitator, the entire system is now under a slight negative pressure and all leaks are from the room into the gas stream.

The I.D. fan in service prior to the conversion was known as a "dirty" fan. It was sized to handle a large gas volume containing a high percentage of water evaporated in the black liquor venturi. The fan required sufficient head to overcome the pressure drop across both venturies as well as the boiler. This fan was rated for 394,000 ACFM at 33 inches of water static pressure at 1085 RPM and required a 1200 horsepower driver. Rather than being located between the boiler and black liquor venturi, it was located after the venturi and wall washes.

The two major problems with this system were:

1. A 25 inch water differential maintained across the venturi and cyclone exerted constant strain on the fan causing numerous mechanical difficulties.
2. Black liquor carry-over from the cyclone necessitated water washing the fan each shift, resulting in a serious corrosion problem for the fan.

These problems have been eliminated in the new system.

The new induced draft fan is located on the discharge side of the precipitator. This fan is rated at 279,000 ACFM at 18 inches of water pressure at 970 RPM and requires only a 780 horsepower driver. Because of the new system configuration, the new fan has less gas volume to handle than the one it replaced and benefits also from the relatively small pressure drop of only a few inches of water developed across the new components of the system (No. 2 economizer and precipitator).

OPERATING COSTS

Chemicals

The reduction in particulate emissions that resulted from the installation of the electrostatic precipitator amounted to approximately 5000 lb/day. This amounted to a total cost savings of $25,000 during fiscal 1973 (based on a unit cost of $29/ton for salt cake).

With the new system it is necessary to maintain a relatively low liquor sulfidity (26-28%) to minimize the emissions of SO_2 which formerly had been scrubbed out in the direct contact evaporator. To keep the sulfidity low, considerable caustic soda is required for chemical makeup in the liquor system. The average monthly usage of caustic for the 1972-1973 fiscal period was 651 tons as compared to an average monthly usage of 365 tons for the 1969-1970 fiscal period. The average annual increase in cost for caustic soda amounted to $288,000 (based on a unit cost of $84/ton). On the other hand, this increased caustic usage did result in a molar-equivalent (on a sodium basis) reduction in salt cake amounting to 508 tons of the latter having a value of $177,000.

Taking both salt cake and caustic soda usages into account, the overall annual increase in chemical cost for liquor makeup is $86,000.

Utilities

Fuel: No change after modification

Steam: Process steam remained basically the same, but distribution changed

Before modification:	212,000	lbs steam/hr produced
	- 20,000	lbs steam/hr sootblowing
	192,000	lbs steam/hr to process
After modification:	272,000	lbs steam/hr produced
	- 40,000	lbs steam/hr sootblowing
	232,000	lbs steam/hr
	- 38,000	lbs steam/hr concentrator
	194,000	lbs steam/hr to process

Power Requirements:

Before modification	3412 HP	$148,400
After modification	3166 HP	137,700
Decrease of	246 HP	$ 10,700

Feedwater:

Before modification	192M	lbs/hr process steam(50% returned)
	20M	lbs/hr boiler IK steam(none returned)
	212M	lbs/hr produced
After modification	194M	lbs/hr process steam(50% returned)
	40M	lbs/hr boiler IK steam(none returned)
	38M	lbs/hr concentrator usage(all returned)
	272M	lbs/hr produced

Additional IK steam required for sootblowing is equivalent to an additional 20,000 lbs feedwater/hr. for an annual cost of $23,500.

Labor Costs

No change in operating labor resulted from the modifications made to No. 3 recovery system.

Maintenance Costs

Maintenance charges incurred by No. 3 recovery boiler, precipitator, and concentrator for the past three years are given in Table 12. The higher repair costs incurred by No. 3 recovery since the 1971 conversion indicates the increasing age of the unit as well as the need for more complete maintenance to insure reliable and low-emission operation.

Table 12

MAINTENANCE COSTS FOR NO. 3 RECOVERY SYSTEM

No. 3 Recovery

		Total Cost	Cost/Month
Before modification:			
Fiscal 1969		$ 69,266	$ 5,770
Fiscal 1970		87,638	7,300
November 1970-April 1971		43,640	7,275
	Avg.	$ 81,395(69-71)	
After modification:			
May 1971-October 1971		$ 43,640	$ 7,275
Fiscal 1972		111,157	9,260
Fiscal 1973		109,241	9,103
	Avg.	$110,199(72-73)	

Precipitator

Fiscal 1971		$ 28,710
Fiscal 1972		19,761
Fiscal 1973		16,606
	Avg.	$ 21,692

Concentrator

Fiscal 1971		$ 18,065(1 effect operation)
Fiscal 1972		17,991(1 effect operation)
Fiscal 1973		23,053(3 effect operation)*
	Avg.	$ 19,703

* Upon completion and startup of No. 4 recovery boiler and auxilliary equipment in the overall system.

A summary of all changes in annual operating costs resulting from the modifications made to the No. 3 recovery system is given below.

Table 13

SUMMARY OF INCREASED OPERATING COSTS RESULTING FROM SYSTEM MODIFICATIONS

Category			Annual Change in Cost($)
Labor			Unchanged
Chemicals			+ 86,000
Auxilliary Fuel			Unchanged
Power			- 10,700
Feedwater			+ 23,500
Maintenance			+ 70,200
	Boiler	+ 28,805	
	Precipitator	+ 21,692	
	Concentrator	+ 19,703	
	Total		$169,000

SECTION XII

EVALUATION OF REDUCED EMISSIONS FROM MODIFIED SYSTEM

The justification for the major modifications made to the No. 3 recovery system was the anticipated reduction in emissions, both gaseous and particulate, necessary to meet the State of Montana regulations. These specified a maximum daily average emission of 17.5 ppm for total reduced sulfur gases (TRS) and a maximum particulate emission of 45.3 lb/hr. (at design solids loading) for No. 3 recovery boiler.

PARTICULATES

Initial particulate tests made on the precipitator following the startup in late April (1971) indicated a relatively low collection efficiency of 95.5%. These tests were summarized earlier in Table 10 (Period 1 summary). The first effective modifications made in January (1972) raised the efficiency to a level of 97.5-98.0% (Period 2 summary). Further modifications made in June (1972) increased the efficiency to 98.5-99.0% (Period 3 summary). The several small mechanical modifications made in December (1972) finally permitted the precipitator to attain its guaranteed collection efficiency of 99.125% based on an incoming design dust loading of 8.0 grains/SDCF.

The modified "controlled odor" No. 3 recovery boiler will meet the stringent emission standards established by the State when operated at design loading (100%). Average particulate emissions have been reduced from 6000 lb/day to 1000 lb/day (41.7 lb/hr.) for a better than 80% reduction overall.

TRS AND SO_2

A weekly summary of TRS and SO_2 data compiled for the post-conversion period (June 1971 through December 1973) is given in Table 6 of Appendix E. This comprehensive data, averaged for three different sulfidity levels, is tabulated below.

Table 14

WEEKLY SUMMARY OF DAILY AVERAGE TRS AND SO_2 DATA (1971-1973)

Sulfidity Range (%)	No. of Data Points(Weeks)	TRS(ppm)		SO_2(ppm)	
		Average	Range	Average	Range
26.1 - 28.0	20	7.1	0-16	32	0-138
28.1 - 31.0	92	9.1	1-25	71	5-279
31.1 - 33.0	8	16.9	6-27	198	43-353

An upward trend in both TRS and SO_2 are evident with an increase in sulfidity levels.

A more detailed analysis of TRS and SO_2 levels at various sulfidity ranges is presented in Tables 15 and 16. Over 300 sets of data representing all of the daily average data for the period December 1972-November 1973 (inclusive) were collected in order to develop this data presentation for three sulfidity ranges. The cumulative percentage (C.P.) data points are plotted on semilog paper in Figures 7 and 8. This graphic presentation indicates the increasing percentage of high levels of both TRS and SO_2 that results as the sulfidity level of liquor increases.

The TRS plot (Figure 7) indicates that over the sulfidity range of 26-31%, approximately 89% of the daily average data falls at or below 17.5 ppm, the Montana Air Emission Standard for TRS. In the higher sulfidity range of 31-33% only 65% of the data conforms to this State standard. This record includes all operating days for a 12-month period and is fairly representative of what can be expected from a well-controlled recovery boiler.

The SO_2 plot (Figure 8) indicates that in the lower sulfidity range of 26-28%, 82% of the daily average data falls at or below 100 ppm, 96% of the data falls below 200 ppm, and 98% below 300 ppm. For the normal sulfidity range of 28-31%, 67% falls below 100 ppm, 92% below 200 ppm, and 96% below 300 ppm. A major upward shift in SO_2 occurs at the higher sulfidity range of 31-33% as was noted in the case of TRS. At this sulfidity level, only 22% of the data falls at or below 100 ppm, 47% below 200 ppm, and 72% below 300 ppm. Even at 400 ppm, 10% of the data is not accounted for.

STACK GAS TEMPERATURE AND MOISTURE CONTENT

Table 17 summarizes the average temperature and moisture content of flue gases measured during the EPA testing program for the various phases of the program. The boiler exit and stack temperatures vary directly with the load. The exact variation cannot be predicted because of the unknown influence of other parameters such as liquor composition, air to liquor ratio, air distribution, and probably most important of all, the degree of boiler plugging and deposit build-up on the furnace tubes. Before the conversion, the stack temperature averaged 170°F for normal boiler loading and sulfidity (28-31%) conditions and the moisture was 43.4 percent. This represented saturated exit gas conditions at mill altitude (3000 ft.) and resulted in a dense plume at all times. Since the conversion, the increased temperature and decreased moisture content give rise to only an occasional visible plume when adverse weather conditions exist.

The reduction in flue gas moisture due to elimination of the direct contact evaporator is greater than the anticipated reduction of 40% calculated at the time preliminary engineering studies were made in 1969.

AIR INFILTRATION INVESTIGATION

The decrease in flue gas moisture from the boiler exit (31.8%) to the

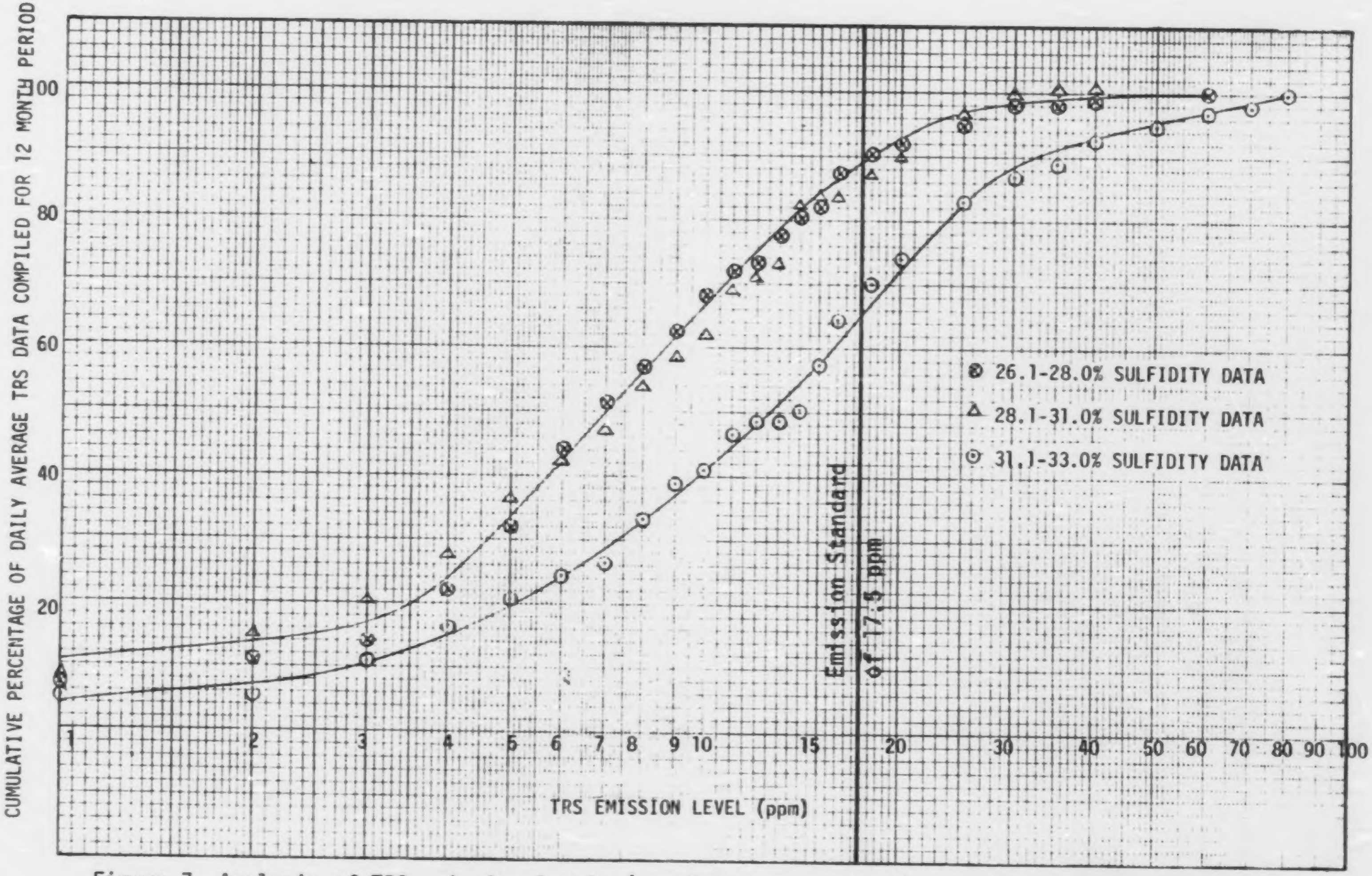


Figure 7 Analysis of TRS emission levels (cumulative percentage) for various sulfidity ranges

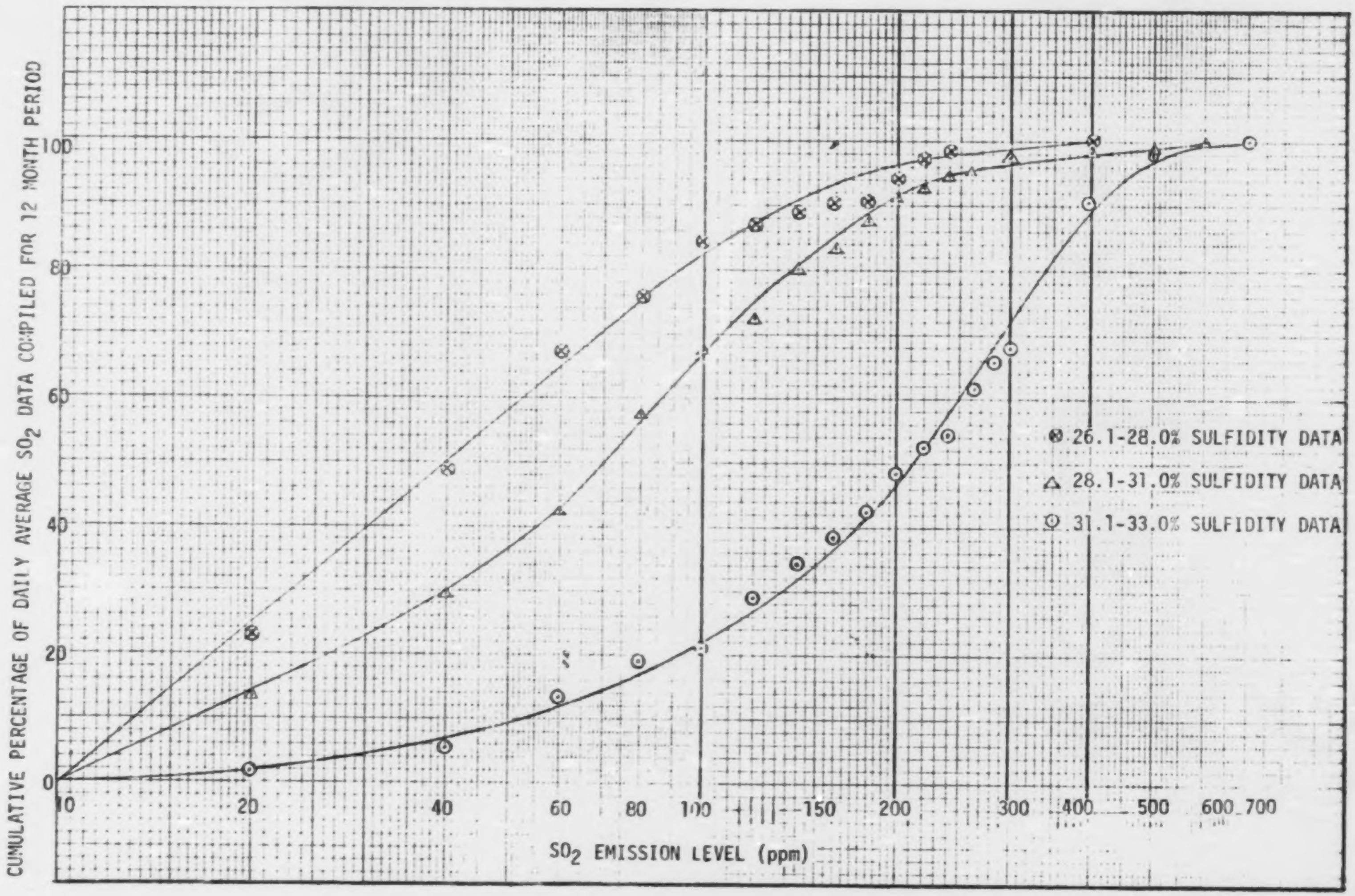


Figure 9 Analysis of SO_2 emission levels (cumulative percentage) for various sulfidity ranges

Table 15

*ANALYSIS OF DAILY AVERAGE VALUES FOR TRS
(for Period of December 1972-November 1973)

TRS Level (ppm)	Total No. Of Data Points	26.1-28.0% Sulfidity Range			28.1-31.0% Sulfidity Range			31.1-33.0% Sulfidity Range		
		No.	%	C.P.	No.	%	C.P.	No.	%	C.P.
1	24	5	7	7	16	8	8	3	5.5	5.5
2	16	3	4	11	13	6.5	14.5	0	0	5.5
3	16	2	3	14	11	5.5	20	3	5.5	11
4	23	6	8	22	14	7	27	3	5.5	16.5
5	27	7	10	32	18	9	36	2	4	20.5
(1-5)	(106)	(23)			(72)			(11)		
6	23	9	12.5	44.5	12	6	42	2	4	24.5
7	15	5	7	51.5	9	4.5	46.5	1	2	26.5
8	22	4	5.5	57	14	7	53.5	4	7	33.5
9	16	4	5.5	62.5	9	4.5	58	3	5.5	39
10	16	4	5.5	68	11	5.5	63.5	1	2	41
(6-10)	(92)	(26)			(55)			(11)		
11	16	3	4	72	10	5	68.5	3	5.5	46.5
12	6	1	1.5	73.5	4	2	70.5	1	2	48.5
13	7	3	4	77.5	4	2	72.5	0	0	48.5
14	9	2	3	80.5	6	3	75.5	1	2	50.5
15	19	1	1.5	82	14	7	82.5	4	7	57.5
(11-15)	(57)	(10)			(38)			(9)		
16	9	4	5.5	87.5	1	0.5	83	4	7	64.5
17	6	0	0	87.5	3	1.5	84.5	3	5.5	70
18	6	2	3	90.5	4	2	86.5	0	0	70
19	6	1	15	92	3	1.5	88	2	4	74
20	3	0	0	92	3	1.5	89.5	0	0	74
(16-20)	(30)	(7)			(14)			(9)		
21-25	20	2	3	95	13	6.5	96	5	9	83
26-30	8	2	3	98	4	2	98	2	4	87
31-35	2	0	0	98	1	0.5	99	1	2	89
36-40	5	1	1.5	99	2	1	100	2	4	93
41-50	1	0	0	99	0			1	2	95
51-60	2	1	1.5	100	0			1	2	97
61-70	1	0			0			1	2	98
71-80	1	0			0			1	2	100
Totals	325	72			199			54		

*Barton Titrator Data

Table 16

*ANALYSIS OF DAILY AVERAGE VALUES FOR SO_2
(for Period of December 1972-November 1973)

SO_2 Level (ppm)	Total No.Of Data Points	26.1-28.0% Sulfidity Range			28.1-31.0% Sulfidity Range			31.1-33.0% Sulfidity Range		
		No.	%	C.P.	No.	%	C.P.	No.	%	C.P.
1-20	44	16	23	23	27	14	14	1	2	2
21-40	51	18	26	49	31	16	30	2	4	6
41-60	42	13	18.5	67.5	25	13	43	4	7.5	13.5
61-80	39	6	8.5	76	30	15	58	3	5.8	19.3
81-100	27	6	8.5	84.5	20	10	68	1	2	21.3
(1-100)	(203)	(59)			(133)			(11)		
101-120	16	2	3	87.5	10	5	73	4	7.5	28.8
121-140	19	1	1.5	89	15	8	81	3	5.8	34.6
141-160	9	1	1.5	90.5	6	3	84	2	4	38.6
161-180	10	0	0	90.5	8	4	88	2	4	42.6
181-200	14	3	4	94.5	8	4	92	3	5.8	48.4
(100-200)	(68)	(17)			(47)			(14)		
201-220	7	2	3	97.5	3	1.5	93.5	2	4	52.4
221-240	5	1	1	98.5	3	1.5	95	1	2	54.4
241-260	6	0	0	98.5	2	1.0	96	4	7.5	61.9
261-280	5	0	0	98.5	3	1.5	97.5	2	4	65.9
281-300	1	0	0	98.5	0	0	97.5	1	2	67.9
(201-300)	(24)	(3)			(11)			(10)		
301-400	16	1	1	100	3	1.5	99	12	22.6	90.5
401-500	5	0			1	.5	99.5	4	7.5	98
501-600	1	0			1	.5	100	0	0	98
601-700	1	0			0			1	2	100
Totals	318	70			196			52		

*Barton Titrator Data

Table 17

FLUE GAS TEMPERATURE AND MOISTURE CONTENT BEFORE AND AFTER CONVERSION

	Boiler Exit		Stack	
	Temp. (°F.)	H_2O Content (Vol.%)	Temp. (°F.)	H_2O Content (Vol.%)
Before Conversion (Normal Load and Sulfidity)	604	30.7	170	43.4
After Conversion				
Low Sulfidity (26-28%)				
High Load (110%)	671	32.4	404	30.3
Normal Load (100%)	616	32.1	388	30.5
Low Load (75%)	547	33.7	350	32.6
Normal Sulfidity (28-31%)				
High Load (110%)	665	31.1	415	29.4
Normal Load (100%)	653	30.7	405	30.6
Load Load (75%)	569	31.5	373	31.4
High Sulfidity (31-33%)				
High Load (110%)	631	31.5	389	30.1
Normal Load (100%)	633	31.7	363	28.7
Low Load (75%)	566	31.4	323	30.6
Averages	617	31.8	379	30.5

Calculation of Moisture Reduction

Original Moisture Content of Stack Gas

$$\left[\frac{\text{vol. of water}}{\text{vol. of dry gas}}\right] = \frac{0.434}{(1-.434)} = 0.767$$

Final Moisture Content of Stack Gas

$$\left[\frac{\text{vol. of water}}{\text{vol. of dry gas}}\right] = \frac{0.305}{(1-.305)} = 0.439$$

Reduction in Moisture Volume (%)

$$\left[\frac{0.767-0.439}{0.767}\right] \quad 100 = 42.8$$

stack (30.5%) for the post-conversion data presented in Table 17 is due to dilution of flue gases with tramp air leaking into the precipitator and connecting duct work. The gas volume measured at the stack was about 12,000 SDCFM higher than the volume at the boiler exit. The oxygen content of flue gases determined at the stack was 1.0-1.5% higher than that measured at the boiler exit. Sonic tests carried out at the precipitator indicated the presence of leaks around the rapper shafts, high voltage insulators and also at the inlet damper.

The precipitator was pressurized and smoke bombs set off inside. The issuing smoke indicated the major leak to be around the inlet guillotine dampers. A metal ring was sealed to the precipitator outer wall and a large plastic bag attached. The time required for the bag to collapse was measured and the total air infiltration through the tile wall computed as 1,000 CFM. Other minor leaks exist at door gaskets, fittings, flanges, shaft seals, etc. These tend to vary as maintenance is performed on the system.

Because of the greater gas flow at the stack than at the boiler exit, precipitator collection efficiency was determined on the basis of total dust discharged (lb/hr.) rather than grain loading (grains/SDCF).

SECTION XIII

EPA TESTING PROGRAM

(OPTIMIZATION OF BOILER OPERATION FOR MINIMUM EMISSIONS)

INTRODUCTION

The testing program carried out at Missoula on the No. 3 recovery system was intended to establish cause and effect relationship between process and operating variables and the resultant emissions, both particulate and gaseous sulfur compounds. With simultaneous measurement of process variables, relationships were developed between pollutant emissions and the following process variables: sulfidity, boiler loading, excess oxygen in the furnace and various ratios of primary, secondary and tertiary air. Optimization of these operating conditions to minimize stack emissions was attempted for three different boiler load conditions and demonstrated for a sufficient duration of time to demonstrate stable operations (anywhere from 12 to 24 hours).

IDENTIFICATION AND RANGE OF OPERATING VARIABLES TO BE INVESTIGATED

Boiler Loading

The design loading on the No. 3 recovery boiler is 1,400,000 lbs of black liquor solids per day at a heating value of 6,600 BTU/lb D.S. (excluding any recirculated or makeup salt cake addition). The three target levels established for boiler loading in the program were 75%, 100%, and 110%, with the actual range of load investigated varying from 73% to 118%.

Excess Oxygen

Excess oxygen was included in the study because it was recognized as an important variable in controlling the TRS emissions from the furnace. The normal operating range is 1.5 to 2.5%. There is considerable variation in the O_2 reading itself and any attempt to maintain the level at any one specific value was considered unrealistic. Therefore, three different ranges of excess O_2 were selected for investigation: 0.5 to 1.5%, 2.0 to 3.0%, and 3.5 to 4.5%.

Liquor Sulfidity

It was felt that average SO_2 emissions were related to the level of liquor sulfidity. Therefore, three levels of sulfidity were selected which resulted in a range of SO_2 emissions from zero to several hundred ppm. The sulfidity target ranges selected were 26 to 28%, 28 to 30%, and 31 to 33%. The gap of 1% between normal and high sulfidity ranges was purposely left to insure a sufficiently large difference in sulfidity level for investigation and analysis.

Air Distribution

Air distribution was thought to affect the emission of all three pollutants being studied. On the No. 3 recovery boiler, combustion air is added at three different levels: primary, secondary, and tertiary. The primary level is at the bottom of the furnace whereas the secondary and tertiary are added at progressively higher levels. The normal percentage ratio of air distribution is 45/40/15 for primary, secondary, and tertiary air respectively. For the purpose of this study, it was proposed to look at two other air distributions as well. The three distributions investigated were:

Location	Low Primary	Normal	High Primary
Primary	35%	45%	55%
Secondary	50%	40%	30%
Tertiary	15%	15%	15%

The tertiary air was maintained at 15% of total air in all cases.

MEASUREMENTS AND TESTS INCLUDED IN STUDY

Figure 9 shows the location of the various instruments used to indicate and record the pertinent information required for process control and data collection. Also shown are the locations of the sampling ports required for particulate collection.

Two particulate sampling points were necessary to determine the concentration of dust in the flue gases both before and after the precipitator. The boiler exit sample ports were located on the rectangular duct work installed between the first and second (new) economizer where the straight run of duct available was conducive to meaningful flow measurements. The precipitator outlet sample ports were located on the main stack at a relatively high elevation but inside the recovery building.

Table 18 summarizes the measurements and tests in the EPA test program.

TESTING PROCEDURES EMPLOYED

TRS and SO_2 Testing

Total reduced sulfur gases (TRS) and sulfur dioxide (SO_2) were continuously measured by means of two Model 400 Barton electrolytic titrators. TRS is expressed as equivalent hydrogen sulfide (H_2S). Both TRS and SO_2 results were reported as parts per million (ppm) by volume on a dry gas basis (SDCF).

Titration is the addition of a measured amount of reagent to a sample until the reactive compounds in the sample have been satisfied (some identifiable end point has been reached). In the Barton titrator, the reagent is free bromine, generated by passing an electric current through

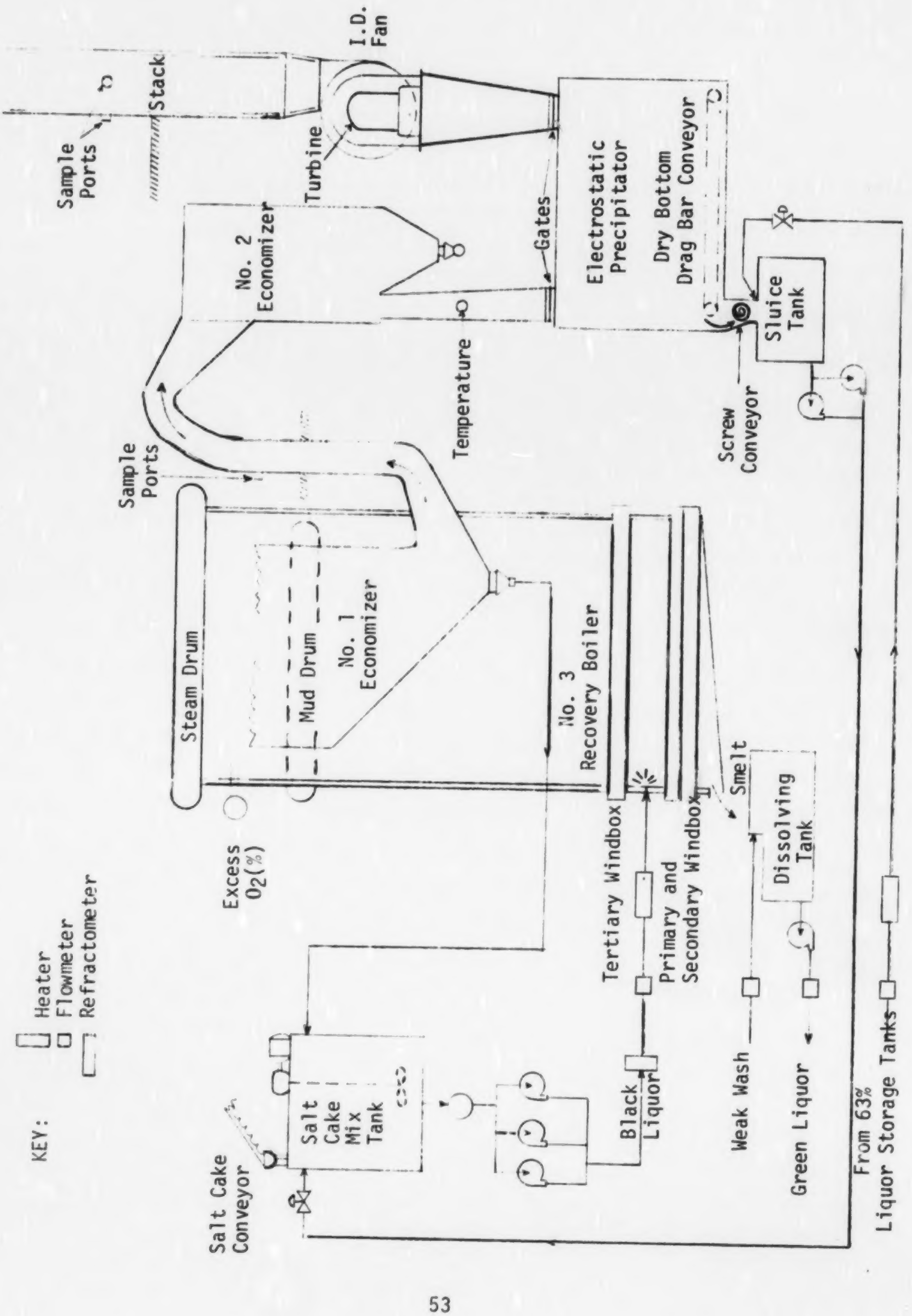

KEY:
Heater
Flowmeter
Refractometer
Salt Cake Conveyor
Salt Cake Mix Tank
Black Liquor
Weak Wash
Green Liquor
From 63% Liquor Storage Tanks
Excess O2(%)
Tertiary Windbox
Primary and Secondary Windbox
Dissolving Tank
Smelt
Steam Drum
Mud Drum
No. 1 Economizer
No. 3 Recovery Boiler
Sample Ports
Temperature
No. 2 Economizer
Gates
Electrostatic Precipitator
Dry Bottom Drag Bar Conveyor
Screw Conveyor
Sluice Tank
Turbine
I.D. Fan
Stack
Sample Ports

Figure 9 Instrumentation and sample points for No. 3 recovery system

Table 18

MEASUREMENTS AND TESTS INCLUDED IN EPA TEST PROGRAM

Item	Means of Data Collections
Black liquor flow to sluice tank	Existing magnetic flow meter, continuously recorded
Black liquor flow to nozzle	Existing magnetic flow meter, continuously recorded
Black liquor density	Measured twice per day
Solids content of liquor	Refractometer (included in project) also check manually twice per day
Salt cake makeup	Existing screw conveyor feed determined by rpm
BTU analysis of black liquor	Determined for each sulfidity level by Babcock and Wilcox laboratory
Temperature of liquor at nozzle	Existing thermometer, manual readout
Nozzle pressure	Existing pressure gauge, manual readout
Primary, Secondary and Tertiary air flows	Existing pressure taps, continuously recorded
Temperature of incoming air	Existing thermocouple, continuously recorded
Excess oxygen	Existing analyzer, continuously recorded
Boiler exit flue gas temperature (outlet #1 economizer)	Existing thermocouple, continuously recorded
Precipitator inlet flue gas temp., (outlet #2 economizer)	Existing thermocouple, continuously recorded
Steam flow	Existing orifice, continuously recorded
Green liquor total alkai, active alkali and sulfide	Wet chemistry analysis
White liquor total alkali active alkali, and sulfide	Wet chemistry analysis
Green liquor flow	Magnetic flowmeter (included in project)
Weak wash flow	Magnetic flowmeter (included in project)
SO_2	Barton titrator (included in project)
TRS	Barton titrator (included in project)
Particulate	Sampled twice per day both at boiler exit and stack

the hydrobromic acid cell solution. A constant flow of sample gas passes through the cell and the sulfur compounds in the sample react with the bromine. The amount of current supplied to the cell is automatically adjusted by the circuit in the control module to produce just enough bromine to continuously maintain end-point conditions. The current flow is thus proportional to the reactive (sulfur) compounds in the sample. A calibration factor converts current flow to parts per million of the measured compounds.

The gas flowing through the reaction cell sweeps out a small amount of bromine. The current required to replace this bromine is the base line reading. The base line can be adjusted and represents the equilibrium concentration of free bromine. The exact value is not critical as long as it is known.

A small sample of flue gas is continuously drawn off at the sample port on the stack and is split into two sample lines going to two separate Barton titrators. One measures the total sulfur gases present in the stack sample. The second measures TRS after a potassium acid phthalate scrubber has removed the SO_2. The SO_2 is calculated by difference. The phthalate solution is purged continuously through a specially designed scrubber to prevent SO_2 carryover. The gas stream then passes through the titration cell where the remaining sulfur compounds are oxidized by bromine. The current flow required to regenerate the consumed bromine from the hydrobromic acid electrolyte is proportional to the amount of sulfur gases present. The rest of the testing apparatus includes a rotometer, micrometering valve, and vacuum pump or water aspirator.

Figure 10 is a schematic flow diagram of the Barton titrator setup used for testing at No. 3 recovery boiler stack.

Probe - A 1/2 inch stainless steel probe is used to extract the gas sample from the stack just under the roof line. The sample stream is split to measure total sulfur compounds and reduced sulfur compounds (TRS).

Scrubber - To measure the reduced sulfur compounds, a scrubber is provided to remove SO_2. The scrubber is an acrylic block, drilled with an "H" shaped chamber. Sample gas is bubbled through 5% potassium biphthalate solution in one leg, and the overflow solution and scrubbed gas are separated in the other leg. Liquid is removed through a seal drop-leg. Scrub solution is metered into the scrubber at 1/2 to 1 cc per minute from a head bottle, using a piece of thermometer tube as a limiting orifice.

Surge Chamber - Each system contains a surge chamber to help level out the short term peaks and valleys. Condensed moisture is also removed at this point.

Cell - The cells are white plastic reaction chambers with an integral bubbler and electrode fitting.

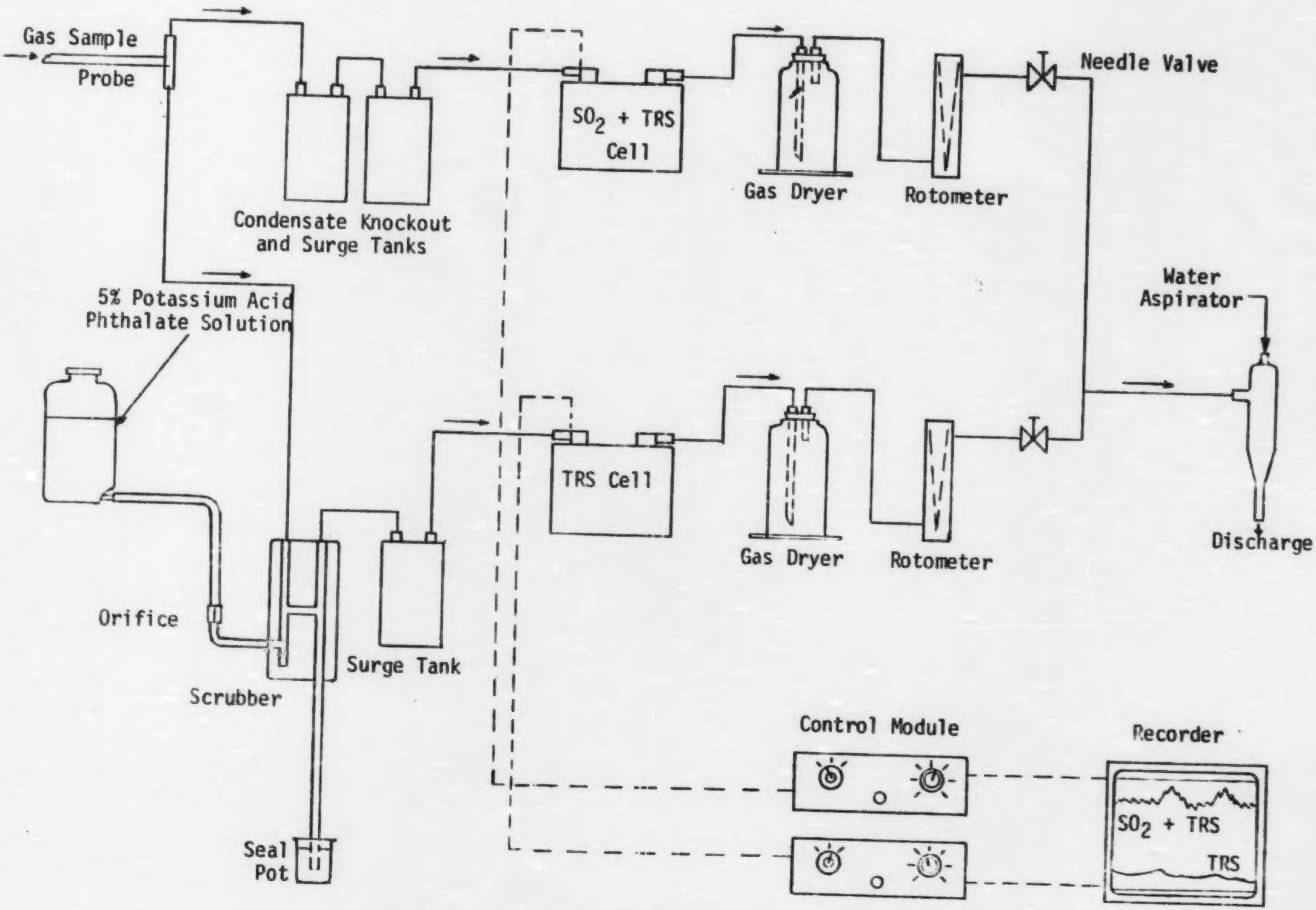

Gas Sample
Probe
Condensate Knockout
and Surge Tanks
SO_2 + TRS
Cell
Gas Dryer
Rotometer
Needle Valve
Water
Aspirator
Discharge
5% Potassium Acid
Phthalate Solution
TRS Cell
Gas Dryer
Rotometer
Orifice
Scrubber
Surge Tank
Seal
Pot
Control Module
Recorder
SO_2 + TRS
TRS

Figure 10 Barton titrator setup

Dryers - Gas washer bottles are filled with activated silica gel to dry the gas leaving the cell. The wet gas is very corrosive from the bromine swept out of the cell. The dryers protect the control valves.

Flowmeter - This is an indicator of the flow rate through the reaction cell. Ball float purge rotometers are used.

Control Valves - Stainless steel needle valves are used to control the flow.

Aspirator - A water aspirator is used to provide vacuum to draw the sample through the system.

The following items are located on the Operator's panel:

Control Module - This is the electronics package that controls the bromine level in the cell and provides a signal to the recorder. On the face of the module is a function switch, which turns the unit on and off, a recorder check button, and a range switch. The range switch selects the cell current, which will give full scale deflection on the recorder. Ranges are from 0.1 to 100 milliamps.

Recorder - A two-pen recorder with a 0-100 scale strip chart is used. This provides a continuous record of TRS and total sulfur emissions.

Integrators - Each pen trace is integrated with time and the total continuously displayed on a six wheel counter.

With increased operating experience, several changes were made to the Barton titrator system.

1. A vacuum pump was replaced with a water aspirator for reduced maintenance and downtime.

2. The cell unit was moved from about 60 feet from the sample point to within six feet. This reduced the response time and eliminated a long length of plastic tubing subject to mechanical damage and leakage. There was also some concern that this long tubing may have been absorbing and desorbing sulfurous gases during rapid concentration changes. This was later found to be untrue.

3. A spinning syringe was originally used for calibrating the Barton titrators. Although this was a satisfactory method, the equipment is delicate, awkward to transport, and requires a source of compressed air. This method was replaced with a motorized syringe, which is more compact and easier to use.

Particulate Testing

Particulate tests were run simultaneously on the boiler exit and the stack with the help of two 2-man testing teams. The majority of tests lasted 77 minutes, corresponding to one complete "sootblowing cycle."

The few exceptions extended over a 2-cycle period (154 minutes). The boiler itself is equipped with eleven IK sootblowers, the No.1 economizer with another three and the No.2 economizer with six sootblowers. These are long rectractable tubes with orifices at the sides of the tip. As the sootblowers spiral in and out of the boiler, high pressure steam blasts salt cake from the outside of the furnace tubes. The IK's are blown on a timed sequence, which repeats every 77 minutes.

Isokinetic sampling could not be easily achieved. The flow is channeled somewhat in the duct and in the high velocity region, maximum flow through the sampling train was below that required for isokinetic sampling. A smaller nozzle could not be used because of plugging. Figure 11 is a graph prepared by NCASI showing the error resulting from non-isokinetic sampling for different size particles. Each curve represents a different average particle size. When most of the dust is smaller than 4.0 microns in size, the error from non-isokinetic sampling is less than 3.0%. Sizing tests conducted on No. 3 recovery boiler by Environmental Science and Engineering, Inc. under another EPA contract (3) showed that at the boiler exit, all of the particulate is between 0.1 and 2.0 microns, introducing an error of no more than 1%.

Because of the high dust loading ahead of the precipitator, dry sampling methods could not be used at this point. A ceramic thimble was tried for particulate testing at the time of precipitator startup but the thimble and nozzle plugged rapidly and not a single test could be completed. The precipitator manufacturer tried the dry thimble method by using several probes and holders preassembled before the test. When one filter plugged, it was removed and replaced with a clean one. For the three tests attempted, 5, 7, and 10 thimbles were used respectively. There was a great deal of time lost while changing probes and because some of the thimbles were removed from the holders in the field, there was a good chance for contamination or loss of dust during the sampling operation. EPA tried a modified EPA train with an extra large filter. This also plugged within 15 minutes and the method was abandoned. Environmental Engineering also attempted to develop a test procedure for particulate determinations ahead of the precipitator using a modified EPA train. A wet scrubbing train illustrated in Figure 4, Appendix C was finally selected for the EPA testing program. This is the same sampling unit Hoerner Waldorf has successfully employed at Missoula for particulate testing since 1969.

Particulate emissions at the stack were measured with an EPA train manufactured by Research Appliance Company. A stainless steel lined "pitobe" was used. The EPA train is illustrated in Figure 6, Appendix C. Only the catch from the front half of the EPA train is used to measure particulate. The impinger train is used only as a condenser so that the moisture content of the gases sampled can be collected and measured. Spot checks of scrubber water showed no detectable sodium using a flame photometer. The justification for using only the front half catch of the EPA train is documented in Section C, pages 24-30 of NCASI Technical Bulletin No. 67, "Comparison of Source Particulate Emission Measurement Methods at Kraft Recovery Furnace Stacks."

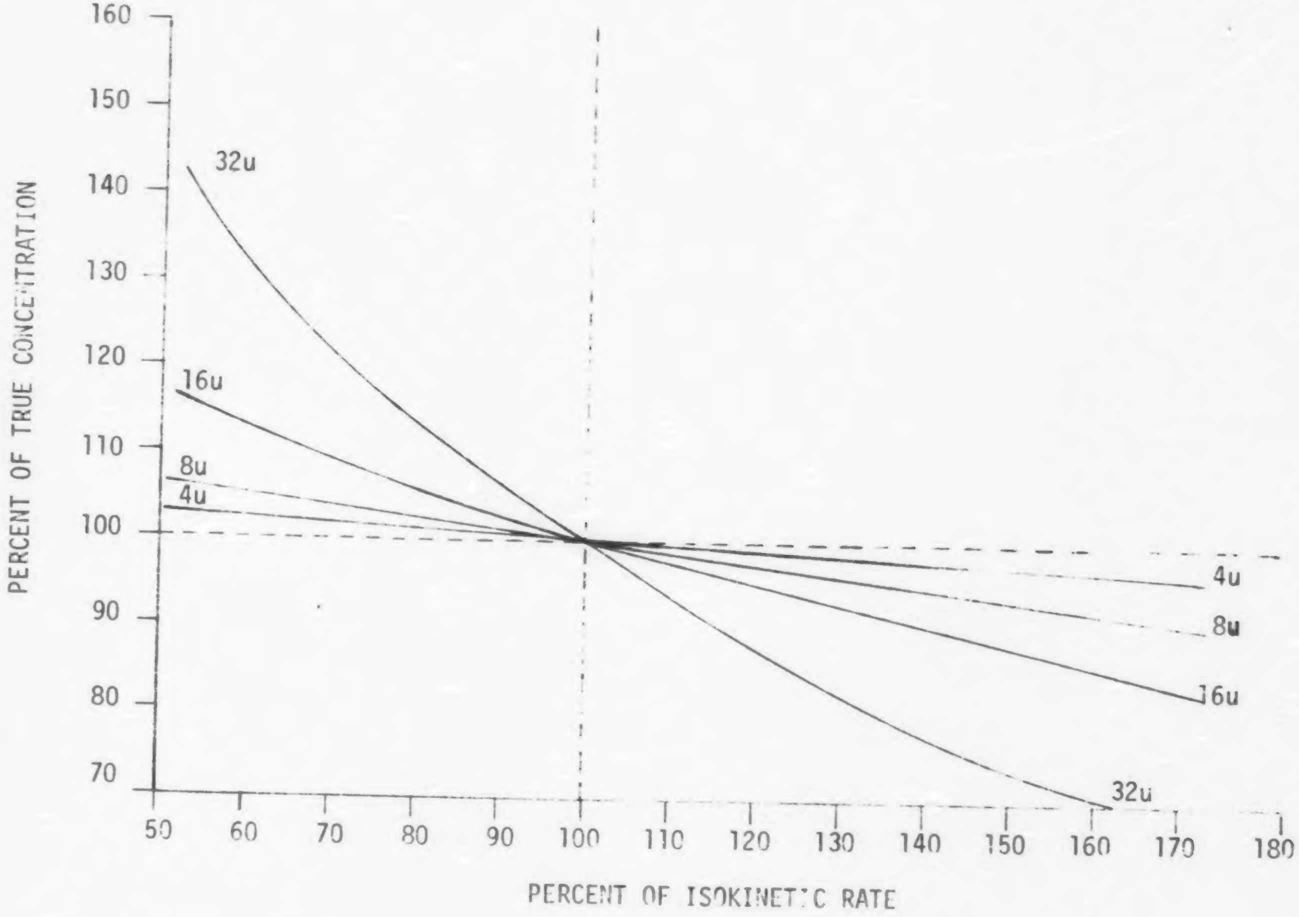


Figure 11 Error introduction from anisokinetic sampling

(Expressed as % of Isokinetic Rate)

The details of the above two testing procedures for the collection of particulate matter from the flue gases and the calculations involved in developing the data are given in Appendix C. Miscellaneous facts of interest related to the particulate testing program are the following:

1. Plugging of the boiler exit probe sometimes occurred at the first bend above the nozzle. This was easily cleared by carefully cleaning the outside of the probe and tapping the probe at the suspected plug. The loosened dust is caught and added to the sample before making up the final volume. Other plugs were washed into the nearest scrubber with water reserved from the original measured 1000 ml.

2. Testers could judge the difference between high and low particulate tests by the buildup of particulate on the outside of the probe.

3. For a normal 77 minute test (equivalent to one complete sootblowing cycle) about 300 ml of condensate is collected at the stack and 450 ml at the boiler exit. Volumes significantly different than this are an immediate flag that abnormal conditions exist in the boiler or that it is a bad test. Leaks, which occassionally developed in the train during a test run, resulted in a low water catch. Such difficulties were encountered only three or four times during the entire testing program period.

4. When dust was just discernible as a haze when looking across the stack at the sample ports, the precipitator collection efficiency was about 99%.

Black Liquor Solids Determination

Samples of liquor were taken during each particulate sampling period. "Sluice liquor" was taken at the discharge of the pump transferring liquor from the 63% storage tank to the precipitator sluice tank. The solids content was determined in the laboratory using a technique requiring in excess of 24 hours to complete. The details of the method and the calculations involved are given in Appendix D.

PLAN OF INVESTIGATION

The testing program for No. 3 recovery boiler was initially scheduled over a three-month period. During each month one of three selected sulfidity ranges was to be maintained: 26 to 28%, 28 to 30%, and 31 to 33%. Once the proper sulfidity level was established three different boiler loads were investigated. At each boiler load, three different air distribution conditions were investigated. Only for normal air distribution conditions (45/40/15) was total air varied to observe the effects of excess oxygen (%) on emissions, particularly TRS. This last investigation was carried out for all sulfidity-boiler load combinations (nine in all). A grand total of 45 different combinations of process variables was programmed in the overall testing program.

At least two sets of data were desired for each condition. There was some difficulty at times establishing the proper set of conditions desired. Excess oxygen (%) and boiler loading were the most difficult variables to control, particularly the latter since the true boiler load could not be accurately calculated until the following day due to the lengthy test procedure required for the determination of black liquor solids. However, of the 45 conditions desired, 42 were actually established during the lengthy study and 126 sets of meaningful data were collected.

In addition to the on-site testing program, composite liquor samples representative of each sulfidity level were collected and forwarded to Babcock and Wilcox for complete analysis, including BTU determinations. Composite samples of particulate matter were also collected and sent off to a commercial testing laboratory for analysis. A summary of these analyses is given in Table 19.

IMPLEMENTATION OF PROGRAM

All testing was carried out during the day shift (8-4). On most days one test was carried out in the morning and one in the afternoon. The rather lengthy and involved procedure for particulate sampling required three to four hours to complete each investigation. Minor changes in operating conditions were made three to four hours before resumption of testing to allow conditions to stabilize.

Sulfidity changes required anywhere from seven to fourteen days to stabilize and reach an equilibrium due to the large total volume of liquors (black, green, and white) in process through the recovery and causticizing systems.

Low Sulfidity Range (26-28%)

The first part of the testing program for No. 3 recovery boiler began on March 5,1973 and was completed on April 4,1973. This was a period of low sulfidity liquor (26-28%) maintained for one month during which time boiler load, total air (% excess O_2) and air distribution were varied to record their effect on particulate emissions, TRS, SO_2, and steam flow.

In general, reliable data was obtained without seriously affecting the operation of No. 3 recovery furnace. The only set of conditions that did not lend themselves to stable operation was the combination of low boiler load, air distribution of 55/30/15, and low excess O_2(%). A blackout of the smelt bed curtailed this furnace condition and it was not repeated.

Table 9 in Appendix G is a detailed tabulation of all the data (39 sets) taken during this low sulfidity period.

Table 19

CHEMICAL ANALYSES OF BLACK LIQUOR AND PARTICULATE SAMPLES

Sample Period	January'73	March-April'73	May-June'73	October'73
Sulfidity Average(%)	29.1	27.3	29.4	31.1
Black Liquor Solids(%)	57.7	60.2	61.4	61.4
Gross Heating Value of Black Liquor(BTU/lb DS)	6520	6510	6560	6560
Elemental Analysis of Black Liquor(% on dry basis)				
Carbon		37.4	37.4	37.0
Hydrogen		4.2	4.2	3.9
Sulfur		4.2	4.6	4.7
Sodium (Na)		19.3	18.7	19.1
Chlorine (Cl)		0.3	0.3	0.3
Inerts		1.2	0.8	0.5
Oxygen(by diff.)		33.4	34.0	34.5
Total Mineral Oxides		27.1	26.0	-
Total Sodium as Na_2O		25.9	25.2	25.7
Particulate Analysis (%)				
Sodium Oxide, Na_2O		43.75	42.87	43.01
Sulfur		19.01	20.97	21.63
Carbon Dioxide		1.90	0.86	0.64
Sodium Sulfate		94.10	92.86	95.72
Sodium Carbonate		4.57	2.07	1.53
Sodium (Na_2) not accounted for stoichiometrically		0.0	0.84	0.25

Normal Sulfidity Range (28-30%)

The second part of the testing program for No. 3 recovery boiler began on April 11, 1973. This was to be a period of normal sulfidity liquor (28-30%) maintained for one month during which time boiler load, total air (% excess O_2) and air distribution were varied in order to determine their effect on particulate emissions. TRS, SO_2, and steam flow. This phase of the testing program was completed on July 17, 1973 following a temporary interruption in testing during June.

Table 10 in Appendix G is a detailed tabulation of all the data (48 sets) taken during the normal sulfidity period.

High Sulfidity Range (31-33%)

The third part of the testing program for high sulfidity (31-33%) liquor began on July 25, 1973. The program was temporarily interrupted during August and September and resumed in October. This portion of the testing program was completed on November 10, 1973. Table 11 in Appendix G is a detailed tabulation of all data (39 sets) taken during the high sulfidity period.

OPERATING EXPERIENCES AND OBSERVATIONS AT DIFFERENT CONDITIONS ESTABLISHED FOR THE TESTING PROGRAM

Black Liquor Solids

The original objective was to hold the true black liquor solids constant at 61 percent during the EPA testing. However, during the course of the project, operations found that higher black liquor solids improved the furnace operation and took steps to raise the percent solids. Table 20 summarizes the increasing trend of black liquor solids during the three testing periods.

Table 20

SUMMARY OF BLACK LIQUOR SOLIDS FOR EACH TESTING PERIOD

Testing Period	% Solids	% Solids Range
Low Sulfidity (26-28)	59.9	58.7 - 61.0
Normal Sulfidity (28-30)	61.6	59.1 - 64.5
High Sulfidity (31-33)	62.9	59.4 - 65.9

The reasons for the increased emphasis on achieving a higher level of black liquor solids are based on the fact that the net BTU's per pound of liquor increases with higher solids. This in turn results in a hotter furnace and in particular, a hotter bed. The operational benefits in maintaining a hotter bed are the following:

1. For a given sulfidity level, SO_2 emissions will be lower. It has been theorized by Borg et al (4) that a hotter bed will vaporize or sublime greater quantities of sodium which will combine with SO_2 to form Na_2SO_4. Thus, SO_2 emissions will decrease with a corresponding increase in particulate emissions. It was generally felt, however, than an increase in particulate would be easier to control (in the high efficiency precipitator) than high SO_2 emissions. The latter cannot easily be contained in a "controlled odor" recovery system that does not have a direct contact evaporator.

2. With a hotter bed, smelt spout pluggage is less of a problem. The unplugging of spouts in an active furnace is a potentially dangerous activity. Explosions can occur when a high smelt run off contacts the weak wash in the dissolving tank.

3. The risk of black outs (loss of fire in the bed) is reduced with a hot bed.

4. Greater steam production is realized with a hotter bed. There is a net BTU increase per pound of liquor entering the boiler and less water to be evaporated with higher liquor solids. This net increase in available heat is utilized for steam production.

Air Distribution

Three different air distributions were studied in this project. They were: 55/30/15%; 45/40/15%; and 35/50/15%. The three figures in each group represent the percentage of primary, secondary and tertiary air, respectively, used to fire the boiler. All three of these air distributions were evaluated for all combinations of boiler loading and sulfidity level established.

Prior to this study, operations had been using a 45/40/15% air distribution as the norm. It was felt this air distribution resulted in a relatively low volume of total combustion air as well as a relatively low and fairly constant boiler exit dust load, both of which tend to improve precipitator efficiency. Boiler testing carried out in the past using a 35/50/15% air distribution indicated erratic and frequent above-design boiler exit grain loadings. (Design boiler exit grain loading is 8.0 gr/SDCF). Operations had some difficulty with the 55/30/15 air distribution and in some instances could not fire the boiler using this air distribution at low boiler loadings (75%). The difficulty centered around the inability to build a smelt bed with a high percentage of primary air. At higher boiler loadings, no difficulties were encountered, nor were the earlier experiences with blackouts and spout plugging repeated.

Boiler Loading

Three different boiler loadings were studied in this project. They were 75%, 100%, and 110% of design solids loading. Three different sulfidity levels and three different air distribution conditions were then investigated at each of the three target boiler loadings.

All 126 sets of data collected during the course of the basic EPA test program have been grouped by boiler loading, sulfidity level, and air distribution and summarized in Tables 21, 22, 23. It is seen that with increasing boiler loading, a higher steam production results. The tabulated data also bears out the fact that as boiler loading increases so does the dust load to the precipitator.

Operations did not have any great difficulties firing the boiler at any of the three boiler loadings. However, boiler pluggage due to salt cake buildup on the economizer tubes was a significant problem at overload conditions. Under these conditions, the boiler would have to be taken off liquor approximately every ten days for cleaning and sometimes the economizer internals would have to be water washed.

Precipitator inlet gas temperatures also increased at overload conditions. This resulted from poor heat transfer at No. 2 economizer because the tubes would become covered with salt cake. The maximum design precipitator inlet temperature is 450°F. This temperature cannot be exceeded due to temperature limitations of the precipitator tile used in precipitator construction. Normal precipitator inlet temperatures are around 400°F. However, during one series of overload testing, the boiler had to be shut down and cleaned because higher temperatures were developing.

High boiler loads also required more frequent air port cleanings to avoid pluggage. If the air ports at the primary air level would plug over, the bed would black out as well as plug the spouts. This extreme was not reached, but closer supervision was required.

Precipitator Efficiency

During the second testing period with normal sulfidity liquor (28-30%) in late April and early May, there was a marked decrease noted in precipitator efficiencies. Operating personnel at first attributed this decrease to the corresponding increase in sulfidity. However, an inspection of the precipitator revealed the need for realignment of the weight frame. After this realignment, the precipitator efficiencies still did not regain the high levels of 99% obtained in March. A second inspection revealed an access door located on the outlet closure plate had been left open during the weight frame realignment. With the closure of this door, subsequent precipitator efficiencies reached earlier high levels. Apparently, the open access door allowed sufficient quantities of salt cake to bypass the plates and wires, resulting in a drop in precipitator collection efficiency. During the remainder of the test program, no efficiency decreased resulted from precipitator malfunctioning. Higher sulfidity did not appear to contribute to result in lower efficiencies during the last portion of the test program.

The particulate data obtained during the above abnormal periods of operation, resulting in precipitator collection efficiencies below 98.5%, were excluded from the final analysis of data described in SECTION XIV of this report.

Table 21a

SUMMARY OF LOW BOILER LOAD CONDITION DATA

Boiler Loading(%)								
Target	75	75	75	75	75	75	75	75
Actual	73-77	74	74-80	86-88	82-86	84-85	81	89-91
Sulfidity(%)								
Target	26-28	26-28	28-30	28-30	28-30	31-33	31-33	31-33
Actual	27-28	27	30-31	28	28	32	33	33
Air Distribution(%)								
Target	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)								
Target	2.0-3.0	3.5-4.5	2.0-3.0	3.5-4.5	0.5-1.5	2.0-3.0	3.5-4.5	0.5-1.5
Actual	2.2-2.5	3.2	2.8-3.0	3.4	1.0-1.5	2.2-2.4	3.0	0.7
Test Dates	3/28,29	3/27	5/29,30	6/26	6/20,25	10/23,24	11/10	10/25
Number of Data Sets Collected	3	2	4	2	3	4	1	2
Total Air(M lbs/hr)	260-262	272	298-307	340	277-302	279-290	305	273-277
Precipitator Inlet Volume(M ft^3/min)	143-146	143	144-167	191-195	145-172	153-172	154	148-164
Particulate Load to Precipitator(lbs/hr)	2745-3212	3190	3120-3950	3466-4192	2521-3241	2061-3119	3302	3094-3300
Particulate Load at Stack(lbs/hr)	8.9-9.4	12.5	14-36	28-30	22-34	16-47	16	17-28
Precipitator Efficiency(%)	99.7	99.6	99.1-99.6	99.1-99.3	98.7-99.3	97.7-99.5	99.5	99.1-99.5
TRS (ppm)	1.9-4.0	2.7	0.8-2.4	9.8	5.4-16	13-17	4.7	45
SO_2 (ppm)	16-21	20	1-51	191	206-329	464-480	124	352
Steam Flow(M lbs/hr)	170-180	170	175-190	205-207	190-207	180-190	210	190-200

Table 21b

SUMMARY OF LOW BOILER LOAD CONDITION DATA

Boiler Loading(%)								
Target	75	75	75	75	75	75		
Actual	76-78	75-76	86-87	83-89	77-85	79-88		
Sulfidity(%)								
Target	26-28	26-28	28-30	28-30	31-33	31-33		
Actual	22-28	25-27	28-30	28	32-33	31		
Air Distribution(%)								
Target	35/50/15	55/30/15	35/50/15	55/30/15	35/50/15	55/30/15		
Excess O_2 (%)								
Target	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0		
Actual	2.0-2.7	2.2	1.9-2.0	2.1-3.0	2.3-3.0	2.3-3.0		
Test Dates	4/2,3	3/30 4/4	6/27,28	7/11,12	11/2,9	11/6,7		
Number of Data Sets Collected	2	2	3	3	3	3		
Total Air(M lbs/hr)	280-288	252-258	312-317	302-312	295-315	254-267		
Precipitator Inlet Volume(M ft^3/min)	145	145-151	153-170	158-167	145-157	139-164		
Particulate Load to Precipitator(lbs/hr)	2857-3548	3277-3627	2145-3568	3184-3956	2811-3142	2363-3212		
Particulate Load at Stack(lbs/hr)	7.2-8.6	3.3-7.9	19-25	36-41	15-33	16-18		
Precipitator Efficiency(%)	99.7-99.8	99.7-99.9	99.0-99.5	98.8-99.0	99.0-99.5	99.3-99.5		
TRS (ppm)	6.6-7.8	1.3-16	19	0-0.2	3.0-21.6	14.2-14.4		
SO_2 (ppm)	42-52	4-120	223-242	36-51	47-260	117-335		
Steam Flow(M lbs/hr)	180-185	180-185	190-201	190-212	190-210	177-200		

Table 22a

SUMMARY OF NORMAL BOILER LOAD CONDITION DATA

Boiler Loading(%)								
Target	100	100	100	100	100	100	100	100
Actual	99-102	100-101	101	97-103	106	100-102	98	105-108
Sulfidity(%)								
Target	26-28	26-28	26-28	28-30	28-30	28-30	31-33	31-33
Actual	27	28	26	31	31	30	32	33
Air Distribution(%)								
Target	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)								
Target	2.0-3.0	3.5-4.5	0.5-1.5	2.0-3.0	3.5-4.5	0.5-1.5	2.0-3.0	3.5-4.5
Actual	2.0-2.4	3.6	1.0	2.2-2.8	3.6	1.2	1.8-2.2	3.6
Test Dates	3/15,26	3/19	3/16	4/30 5/1	5/2	5/4	10/18,19	10/29
Number of Data Sets Collected	4	2	2	4	1	2	3	2
Total Air(M lbs/hr)	343-366	384	325-327	375-383	419	346-357	331-342	385-404
Precipitator Inlet Volume(M ft^3/min)	189-209	200-216	182-183	213-227	211	190	172-187	197-198
Particulate Load to Precipitator(lbs/hr)	2756-4297	3619-4679	3691-4350	3976-5001	4694	4565-4821	3523-3720	4031-4073
Particulate Load at Stack(lbs/hr)	26-34	37-40	32-34	57-81	137	27-39	24-42	50-57
Precipitator Efficiency(%)	98.9-99.4	98.9-99.2	99.1-99.3	98.0-98.9	97.5	99.1-99.4	98.8-99.4	98.6-98.8
TRS (ppm)	4.6-4.9	0.9	15.9	1.5-1.7	4.1	58	17-74	6.6
SO_2 (ppm)	13-34	46	13.4	28-128	17	96	295-433	151
Steam Flow(M lbs/hr)	230-235	230	232-235	230-250	240	235-240	225-230	225-230

Table 22b

SUMMARY OF NORMAL BOILER LOAD CONDITION DATA

Boiler Loading(%)							
Target	100	100	100	100	100	100	100
Actual	105-107	96-100	101-103	105-106	95-105	95-104	92-99
Sulfidity(%)							
Target	31-33	26-28	26-28	28-30	28-30	31-33	31-33
Actual	33	27-28	27-28	29-30	29-31	32-33	31-33
Air Distribution(%)							
Target	45/40/15	35/50/15	55/30/15	35/50/15	55/30/15	35/50/15	55/30/15
Excess O_2 (%)							
Target	0.5-1.5	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
Actual	2.0	2.2-2.4	2.5-3.5	2.0-2.4	2.4-2.8	2.6	2.4-3.0
Test Dates	10/30	3/20,21	3/22,23	5/7,8	4/24,26 5/9,11	11/1,2	8/6 11/5,6
Number of Data Sets Collected	2	4	4	4	8	3	5
Total Air(M lbs/hr)	338-349	370-373	340-371	397-419	343-382	350-366	328-342
Precipitator Inlet Volume(M ft^3/min)	157-175	193-209	191-218	203-217	189-214	182-195	186-194
Particulate Load to Precipitator(lbs/hr)	3828-4102	3001-3881	3531-4248	5200-6794	3761-5070	3639-4002	2640-5163
Particulate Load at Stack(lbs/hr)	32-35	28-32	31-43	61-102	32-52	26-29	41-88
Precipitator Efficiency(%)	99.1-99.2	99.1-99.3	99.0-99.2	98.1-98.9	98.7-99.4	99.3	97.8-99.6
TRS (ppm)	18.1	7.3-7.5	9.5-13.9	2.6-4.5	1.0-3.7	16-24	6.3
SO_2 (ppm)	77	44-55	63-77	24-42	11-122	215-256	291
Steam Flow(M lbs/hr)	225-230	223-225	225-232	235-245	225-240	220-235	218-225

Table 23a

SUMMARY OF HIGH BOILER LOAD CONDITION DATA

Boiler Loading(%)								
Target	110	110	110	110	110	110	110	110
Actual	108-111	108-110	106-114	110-111	110	110-117	109-113	105-108
Sulfidity(%)								
Target	26-28	26-28	28-30	28-30	28-30	31-33	31-33	31-33
Actual	27-28	27	28-29	27-28	28	32	32	33
Air Distribution(%)								
Target	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)								
Target	2.0-3.0	0.5-1.5	2.0-3.0	3.5-4.5	0.5-1.5	2.0-3.0	3.5-4.5	0.5-1.5
Actual	2.0	0.7	2.4-2.5	3.3	1.0	2.0-2.2	3.2	0.8
Test Dates	3/5,6	3/7	4/11,12, 4/16	4/17	4/13	7/25,26	7/30	8/2
Number of Data Sets Collected	4	2	5	2	2	5	2	2
Total Air(M lbs/hr)	391-395	367-377	405-424	428-429	388-392	370-398	403-409	356-374
Precipitator Inlet Volume(M ft^3/min)	217-231	209-214	218-234	231-237	216-217	201-216	206-215	189-222
Particulate Load to Precipitator(lbs/hr)	4303-5408	5236-5370	3692-5671	4384-5100	4440-5107	4181-6195	4382-4954	4864
Particulate Load at Stack(lbs/hr)	53-69	74	97-119	81-106	51-64	50-77	65-72	72
Precipitator Efficiency(%)	98.5-99.0	98.6	97.3-98.8	97.6-98.4	98.8	98.6-98.9	98.5-98.6	98.5
TRS (ppm)	0.1-2.0	25.5	0.9-10.1	1.8	26.5	7.6-21	11.4	6.8
SO_2 (ppm)	9-13	18.5	39-148	16.5	196	215-353	40	280
Steam Flow(M lbs/hr)	245-255	250-255	240-260	250-255	255-260	235-245	235	240

Table 23b

SUMMARY OF HIGH BOILER LOAD CONDITION DATA

Boiler Loading(%)								
Target	110	110	110	110	110			
Actual	106-108	116-118	107-116	110	105-106			
Sulfidity(%)								
Target	26-28	26-28	28-30	28-30	31-33			
Actual	27-28	28	28-29	30	31			
Air Distribution(%)								
Target	35/50/15	55/30/15	35/50/15	55/30/15	35/50/15			
Excess O_2 (%)								
Target	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0			
Actual	1.5-1.7	2.4-2.7	2.0	2.0	2.1			
Test Dates	3/8,9	3/12,13	4/18,23	4/27	7/31			
Number of Data Sets Collected	4	4	3	2	2			
Total Air(M lbs/hr)	415-416	386-401	415-416	376	376-393			
Precipitator Inlet Volume(M ft^3/min)	220-231	235-248	215-224	219-225	200-202			
Particulate Load to Precipitator(lbs/hr)	5373-6295	4019-6400	4882-5848	4888-5104	4039-4600			
Particulate Load at Stack(lbs/hr)	48-66	84-98	49-110	58-64	51-52			
Precipitator Efficiency(%)	99.0-99.2	97.6-98.7	98.0-99.2	98.8-98.9	98.7-98.9			
TRS (ppm)	3.5-4.0	2.5-2.6	4.8-8.4	1.9	18			
SO_2 (ppm)	15.5-17.5	51-78	27-36	52	455			
Steam Flow(M lbs/hr)	255-260	245-260	250-255	240-245	220-225			

Whenever the precipitator was down for cleaning or to permit boiler cleaning, it took at least 24 hours for the electrical readings to settle down. This can only be explained by cold moist air entering the precipitator when inspection doors are open, causing the salt cake to set up on the wires. Because of the affinity of salt cake for water, the salt cake will actually grow on the wires, eventually building up to the point of causing sparking. During the first 24 hours of operation, the precipitator is actually "drying out." When it is dry, most of the salt cake can be rapped from the wires and normal operation will return.

SECTION XIV

DATA ANALYSIS AND DISCUSSION OF RESULTS

At the completion of the EPA testing program it was possible to analyze all the data (126 sets) and establish the relationships between recovery boiler emissions (TRS, SO_2, and particulate) and the various operating parameters monitored such as boiler loading, liquor sulfidity, total air flow, air distribution, and excess oxygen maintained at the boiler exit. This analysis was accomplished statistically with the aid of an IBM System 370 (Model 135) computer using Multiple Regression Analysis.

The method of least squares was used to derive the several equations which best express the relationships developed from the extensive data available for analysis. This method of analysis minimizes the weighted sum of squares of deviations of the data from the function being fit.

CORRELATION MATRIX DEVELOPMENT AND STEPWISE MULTIPLE REGRESSION ANALYSIS

All the data were processed by the computer program in order initially to establish a matrix of the correlation coefficients for each variable with all other variables. This matrix contained 36 different correlation coefficients which indicated the degree of association existing between the variables. The eighteen coefficients listed in the table on page 75 show the relationships between the independent variables (operating parameters) and the dependent variables (emissions).

Once the correlation matrix was established, a stepwise multiple regression analysis was performed on each dependent variable. The result was an overall linear equation that expressed the cumulative relationships of the various independent variables on each dependent variable.

A "coefficient of multiple determination" was also computed. It is commonly noted as "R^2" and indicates the proportion of the variance in the dependent variable which is accounted for by the relationship with each independent variable. R-squared values can only fall between zero and one. A low coefficient would usually indicate that the dependent variable was not being adequately represented by the independent variables selected in the equation.

Although the total air flow might be considered an independent variable, it was actually pre-determined to a large extent by the boiler loading condition established and the desired excess oxygen target. The very high coefficient of 0.906 obtained between total air flow and boiler loading bears this out. The presence of total air flow as an independent variable when first carrying out the stepwise multiple regression analysis on particulate emissions resulted in its predominance over and exclusion of boiler loading in the overall analysis. By excluding total air flow from this part of the analysis, this problem was resolved.

The results of the statistical analyses can be more easily understood by examining the summaries on the next two pages.

For example, in the analysis of Boiler Exit Dust Load, the most significant independent variable affecting this emission was found to be boiler loading. The R-SQ (R^2) value of 0.673 is a measure of the proportion of variation in the dependent variable (boiler exit dust load) that is accounted for by the linear association of the independent variable (boiler loading) included in the equation. The second most significant (contributory) independent variable is sulfidity which brings the cumulative R-SQ value up to 0.700 (70%). Introducing additional independent variables into the overall linear equation relationship does not improve the R-SQ value. The remaining 30% of variation in the dependent variable is attributed to the influence of other variables not monitored,as well as the random fluctuations in the data resulting from test procedures or instrumentation variability. Other variables not measured that are recognized as affecting emissions are smelt bed height, bed temperature, and the degree of air turbulence in the boiler.

The "F" Value is a measure of the statistical significance of the relationships being developed, the higher the "F" Value the greater the significance.

The results of this stepwise analysis are the following:

Boiler Exit Dust Load

Boiler exit dust load was found to be primarily affected by boiler loading and to a much lesser extent by sulfidity. Of the 70% of total variation in emissions accounted for by these two independent variables, 97% of that portion was attributable to boiler loading and only 3% to sulfidity. No further improvement (increase) was obtained in the "coefficient of multiple determination ($\leq R^2$)" when the other two independent variables, excess oxygen and air distribution, were taken into account.

Precipitator Outlet Dust Load

The particulate emission from the precipitator (sampled at the stack) was found to be primarily dependent on boiler loading and to a very minor degree on sulfidity in the linear equation developed for these two independent variables. Of the 71.7% of total variation in emissions accounted for by these two variables, 99% of that portion was attributable to boiler loading. Taking the other two independent variables into account, 72.1% of the total variation in commissions was accounted for.

The Correlation Matrix Using Daily Average Data Points

Independent Variables Examined:	Air Distribution, Boiler Loading, Sulfidity, Excess Oxygen, Total Air Flow
Dependent Variables Analyzed:	TRS Emissions, SO_2 Emissions, Boiler Exit Dust Load, and Precipitator Outlet Dust Load

1. Summary of Correlation Coefficients for Dependent and Independent Variables

	Dependent Variables			
	Boiler Exit Dust Load	Precipitator Outlet Dust Load	TRS	SO_2
Independent Variables(IV)				
Air Distribution	-0.008	0.049	-0.094	-0.088
Boiler Loading	0.821	0.844	0.051	0.064
Sulfidity	-0.129	0.106	0.256	0.574
Total Air Flow	*	*	-0.104	-0.204
Excess Oxygen	-0.235	-0.175	-0.413	-0.217

2. Boiler Exit Dust Load Analysis

Significant Variable	"F" Value	$**\Sigma R^2$
1. Boiler Loading	119.57	0.673
2. Sulfidity	66.42	0.700
3. Excess Oxygen	43.60	0.700
4. Air Distribution	32.13	0.700

Multiple Linear Equation for Two Independent Variables

Boiler Exit Dust Load = 59.5 (Boiler Loading %) - 70.2 (Sulfidity %) + 398

Relative Contribution of IV: 97% 3%

* Excluded from analysis due to complications in stepwise multiple regression analysis resulting from high correlation (0.906) of Total Air Flow and Boiler Loading.

** Coefficient of Multiple Determination (Percentage of total variability accounted for by relationship between dependent and independent variables).

3. Precipitator Outlet Dust Load Analysis

Significant Variable	"F" Value	ΣR^2
1. Boiler Loading	143.59	0.712
2. Sulfidity	72.37	0.717
3. Air Distribution	48.30	0.721
4. Excess Oxygen	35.58	0.721

Multiple Linear Equation for Two Independent Variables

Precipitator Outlet Dust Load -
1.36 (Boiler Loading %) -0.7 (Sulfidity %) -112

Relative Contribution of IV: 99% 1%

4. TRS Emission Analysis

Significant Variable	"F" Value	ΣR^2
1. Excess Oxygen	11.90	0.170
2. Sulfidity	10.28	0.265
3. Total Air Flow	7.28	0.281
4. Boiler Loading	5.87	0.299
5. Air Distribution	4.97	0.315

Multiple Linear Equation for Two Independent Variables

TRS Emissions = 1.97 (Sulfidity %) -8.68 (Excess O_2%) -27.6

Relative Contribution of IV: 30% 70%

5. SO_2 Emission Analysis

Significant Variable	"F" Value	ΣR^2
1. Sulfidity	28.47	0.329
2. Excess Oxygen	19.98	0.412
3. Total Air Flow	15.97	0.461
4. Boiler Loading	12.58	0.478
5. Air Distribution	10.79	0.500

Multiple Linear Equation for Two Independent Variables

SO_2 Emissions = 37.6 (Sulfidity %) -54.6 (Excess O_2%) -857

Relative Contribution of IV: 85% 15%

TRS Emissions

The total reduced sulfur (TRS) gas emissions were found to be primarily dependent on excess oxygen levels and sulfidity. It is quite revealing and disappointing that only 26.5% of the variations in TRS were accounted for by these two variables. Of this total, 70% of that portion was attributable to excess oxygen and 30% to sulfidity. Taking into account all five of the independent variables, only 31.5% of the variation in TRS was accounted for.

SO_2 Emissions

The sulfur dioxide (SO_2) emissions were found to be primarily dependent on sulfidity and excess oxygen. Of the 41.2% of total variation in SO_2 emissions accounted for by these two variables, 85% of that portion was attributable to sulfidity and 15% to excess oxygen. Taking the other three independent variables into account, 50% of the variation in SO2 was accounted for.

POLYNOMIAL REGRESSION ANALYSIS

Once having established the primary relationships existing between the four dependent variables and the independent variables, straight line equations could be established for further analysis. A regression line was fit to the data by the method of least squares, the most significant independent variable being selected in each case to give the most meaningful relationship. These results are summarized on the next page.

POLYNOMIAL REGRESSION ANALYSIS SUMMARY

1. Boiler Exit Dust Load (Y) vs. Boiler Loading (X) - Figure 12
   - a. All data combined (n = 125) $Y = 62.1X - 1940$
2. Precipitator Outlet Dust Load (Y) vs. Boiler Loading (X) - Figure 13
   - a. All data combined (n = 108) $Y = 1.33X - 89$
3. TRS Emission (Y) vs. Excess O_2 (X) - Figures 14 and 19
   - a. All data combined (n = 67) $Y = 29.7 - 8.3X$
   - b. Separation of data by sulfidity level
     - low sulfidity (n = 22) $Y = 16.0 - 4.2X$
     - normal sulfidity (n = 27) $Y = 30.9 - 9.8X$
     - high sulfidity (n = 18) $Y = 56.7 - 15.6X$
4. Log SO_2 Emissions (Y) vs. Sulfidity (X) - Figures 15 and 20
   - a. All data included (n = 69) $Y = .13X - 2.0$
   - b. Data separation by excess O_2 level
     - low excess O_2(0-1.95%) (n = 15) $Y = .16X - 2.7$
     - normal excess O_2(2.00-3.00%) (n = 45) $Y = .13X - 1.9$
     - high excess O_2(3.10-4.00%)(n = 9) Analysis not significant
5. Total Air Flow (Y) vs. Excess O_2 (X) for only 45/40/15 Air Distribution
   - a. separation of data by boiler load
     - low loading (n = 21) Analysis not significant
     - normal loading (n = 22) $Y = 310.5 + 22.88X$
     - high loading (n = 25) $Y = 358.5 + 18.48X$
6. Total Air Flow (Y) vs. Boiler Loading (X) - Figures 16 and 21 (TAF "corrected" to 2.0% excess oxygen prior to analysis)
   - a. All data combined (n = 126) $Y = 27.3 + 3.37X$
   - b. Separation of data by air distribution
     - 35/50/15 (n = 28) $Y = 19.2 + 3.59X$
     - 45/40/15 (n = 67) $Y = 33.7 + 3.28X$
     - 55/30/15 (n = 31) $Y = 16.9 + 3.41X$
7. Steam Production (Y)vs. Boiler Loading (X) - Figure 17
   - a. All data combined (n = 125) $Y = 37.8 + 1.9X$
8. Precipitator Collection Efficiency (Y) vs. Inlet Gas Volume (X) - Figure 18
   - a. All data combined (n=107) $Y - 100.78 - .009X$

Some discretion was used in data input for this analysis. In the case of Precipitator Outlet Dust Load data, several sets of data resulted in calculated precipitator efficiencies below 98.5%. As previously indicated in SECTION XIII, investigation into precipitator operation revealed abnormal conditions that resulted in high particulate emissions at the stack and consequent low collection efficiencies. For this reason these questionable sets of data (14 in all) were not included in the statistical analysis carried out on precipitator outlet dust load, the results of which are shown in Figure 13.

In the case of TRS and SO_2 emissions, average data taken over a period of approximately eight hours corresponding to the overall period of particulate testing on a particular day was utilized in the program to improve somewhat the variability of the data and also to make the analysis more relevant to daily average data routinely compiled by the mill. Further, in the case of SO_2 a log transformation of data was used to eliminate the large spread of SO_2 data encountered.

Figures 12 - 21 inclusive illustrate the major relationships established from the data analysis. Confidence limits of 95% were also calculated for the emissions of the TRS, SO_2,and particulate in order to predict the range of the individual values for the dependent variable in each case. These confidence limits are indicated by the dotted lines in Figures 12, 13, 14, and 15 and indicate the spread anticipated for 95% of all possible data points.

For the Boiler Exit Dust Load relationship shown in Figure 12, the average dust load at 100% boiler loading is 4270 lb/hr. However, the probable range of data at this boiler loading would be 3000 to 5550 lb/hr. It is interesting to note that the maximum dust load emission from the No. 3 recovery boiler at design load indicated by Babcock and Wilcox is 5520 lb/hr. (8.0 gr/SDCF). This value agrees very well with the upper statistical limit established from the actual test data.

Figure 13 gives the relationship between Precipitator Outlet Dust Load and boiler loading. At design boiler loading (100%), the average particulate emissions from the precipitator are 44 lb/hr. This value is within the Montana State Emission Standard for No. 3 recovery, calculated to be 45.3 lb/hr. Figure 13 indicates a probable range of 21 to 66 lb/hr. for particulate emissions at 100% boiler loading. This range of values, as well as the general average, is well supported by Period 4 data found in Table 10.

The recent installation of a Lear Siegler Transmissometer on No. 3 recovery stack to monitor particulate emissions on a continuous basis and the more stable operation of the recovery boiler under relatively fixed conditions of air distribution, excess oxygen, and liquor sulfidity tend to reduce the variability or range of particulate emissions at any given boiler loading.

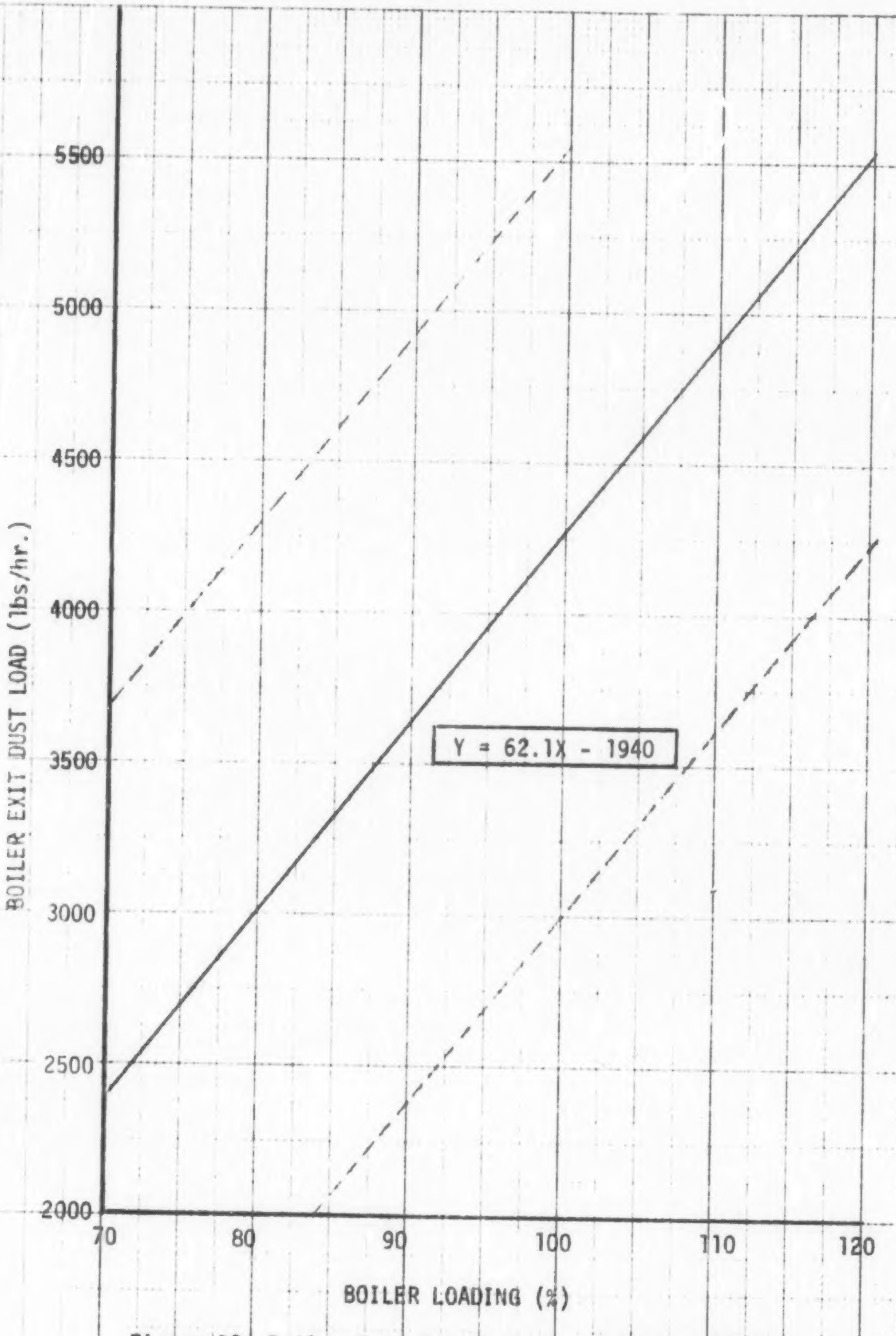


Figure 12 Boiler Exit Dust Load vs. Boiler Loading with 95% Confidence Limits for Individual Data Points

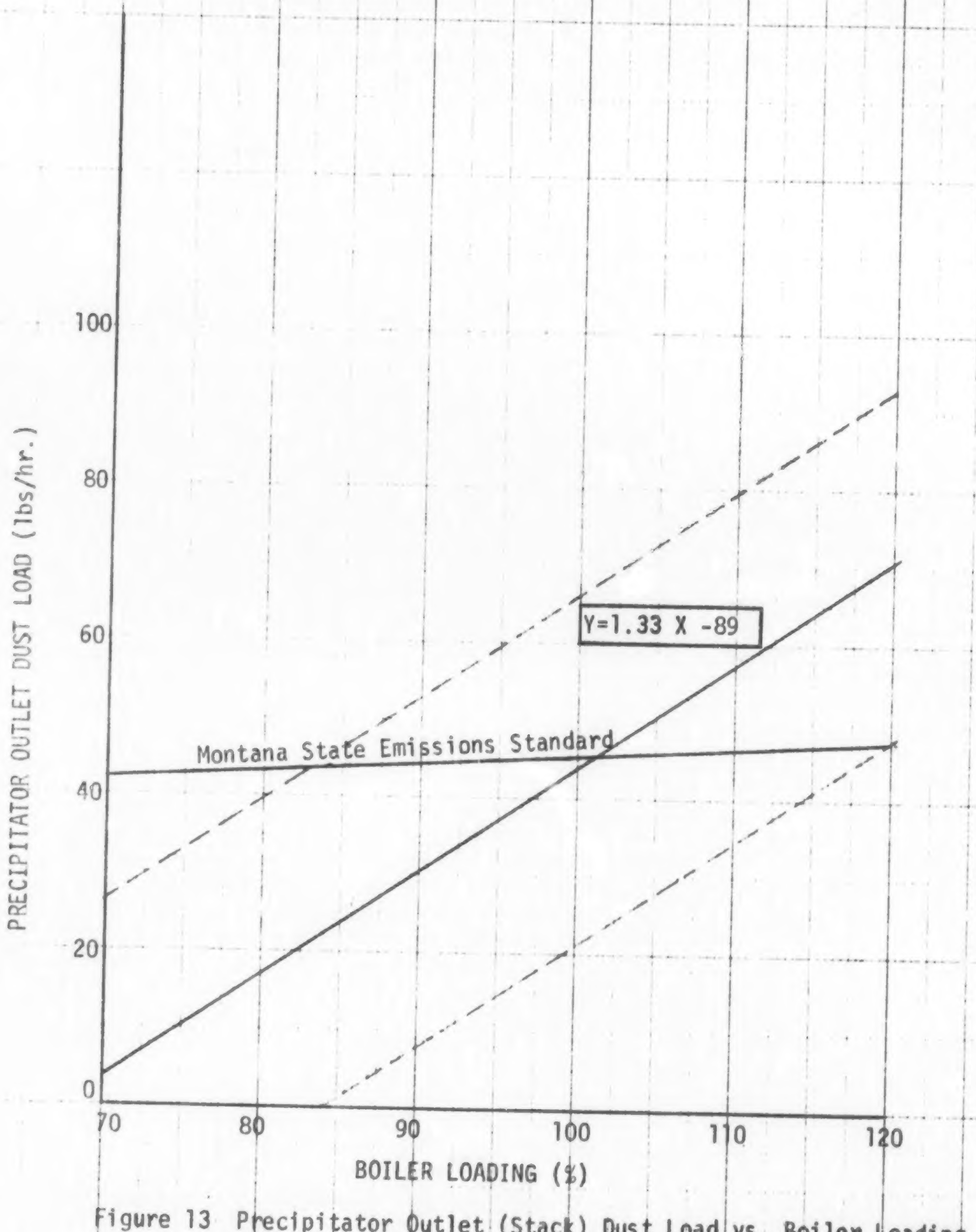


Figure 13 Precipitator Outlet (Stack) Dust Load vs. Boiler Loading with 95% Confidence Limits for Individual Data Points

Figure 14 gives the relationship between TRS emissions and excess oxygen. The regression analysis of all EPA test data collected over wide range of operating conditions indicates that an excess oxygen level of at least 1.5% must be maintained so that the daily average TRS emissions from the boiler do not exceed the Montana State Emission Standard of 17.5 ppm. The 95% confidence limits indicate a probable range of zero to 33 ppm for TRS emissions at a "normal" excess oxygen level of 2.5%. However, under normal conditions of boiler operations with more stable conditions of liquor sulfidity, air distribution, and excess oxygen, the 95% confidence limits would be considerably reduced.

Figure 15 gives the relationship between SO_2 emissions and liquor sulfidity. The regression analysis indicates that average SO_2 emissions can be maintained below 100 ppm if the sulfidity level does not exceed 31%. The 95% confidence limits indicate a probable range of SO_2 emissions from 12 ppm to 870 ppm at the 31% sulfidity level. At a sulfidity level of 26% the range is 2.6 to 204 ppm.

Figure 16 gives the relationship between Total Air Flow and boiler loading. This is a basic relationship that does not require a statistical analysis for confirmation. The application of statistics to define a meaningful regression analysis in this case was somewhat more complex than the other relationships examined. Total air flow requirements are primarily determined by the amount of black liquor solids fed to the boiler that require complete combustion. It was recognized that total air was affected by the excess oxygen level maintained at the boiler exit and possibly also by the air distribution between primary, secondary, and tertiary air flows. In order to establish a meaningful relationship between total air flow and boiler loading, the effects of both air distribution and excess oxygen variations had to be minimized or eliminated entirely from the data. This was accomplished by taking only the normal air distribution (45/40/15) data and establishing the regression analysis for total air flow vs. excess oxygen. Once this was done, total air flow data was "corrected" to 2.0% excess oxygen in order to get all data points on the same basis for further analysis. It was found that approximately 20,000 lb/hr. of air was necessary to increase the excess oxygen level by 1% (from 1.5% to 2.5%). "Corrected" total air flow data was then used for the regression analysis with boiler loading and a meaningful relationship was established. Figure 16 indicates that at 100% boiler loading the average total air flow required to maintain 2.0% excess oxygen is 365,000 lb/hr. The 95% confidence limits indicate a probable range of 305,000 to 425,000 lb/hr. at 100% load.

Figure 17 gives the relationship between steam production and boiler loading. The regression analysis indicates that for 100% boiler loading the average steam generated by the No. 3 recovery boiler is 228,000 lb/hr. This is fairly close to the 235,000 lb/hr. rating for the boiler at design load. At 75% boiler loading the steam availability is 181,000 lb/hr. and at 110% boiler loading the steam availability is 247,000 lb/hr.

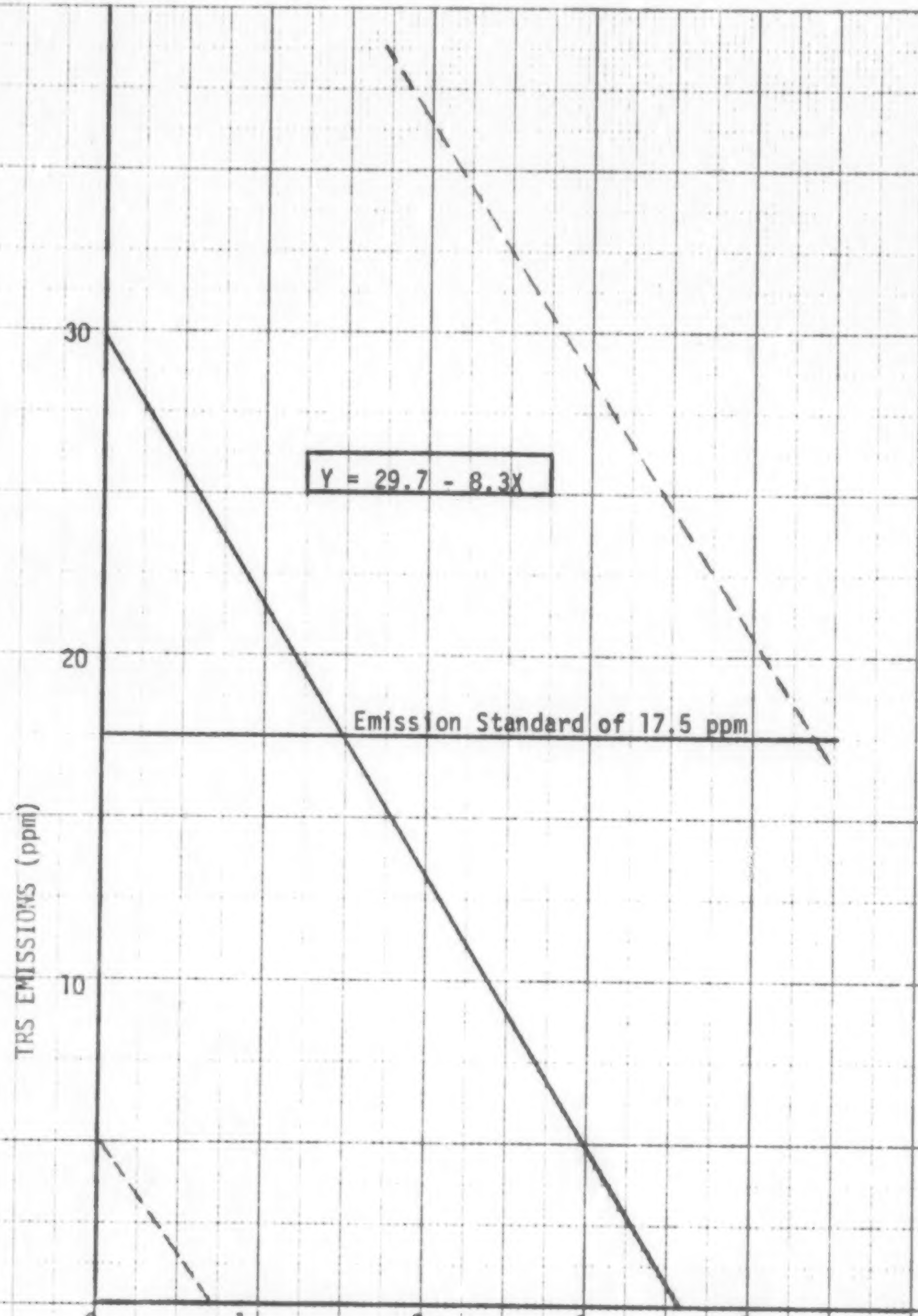


Figure 14 TRS Emission vs. Excess Oxygen with 95% Confidence Limits for Individual Data Points

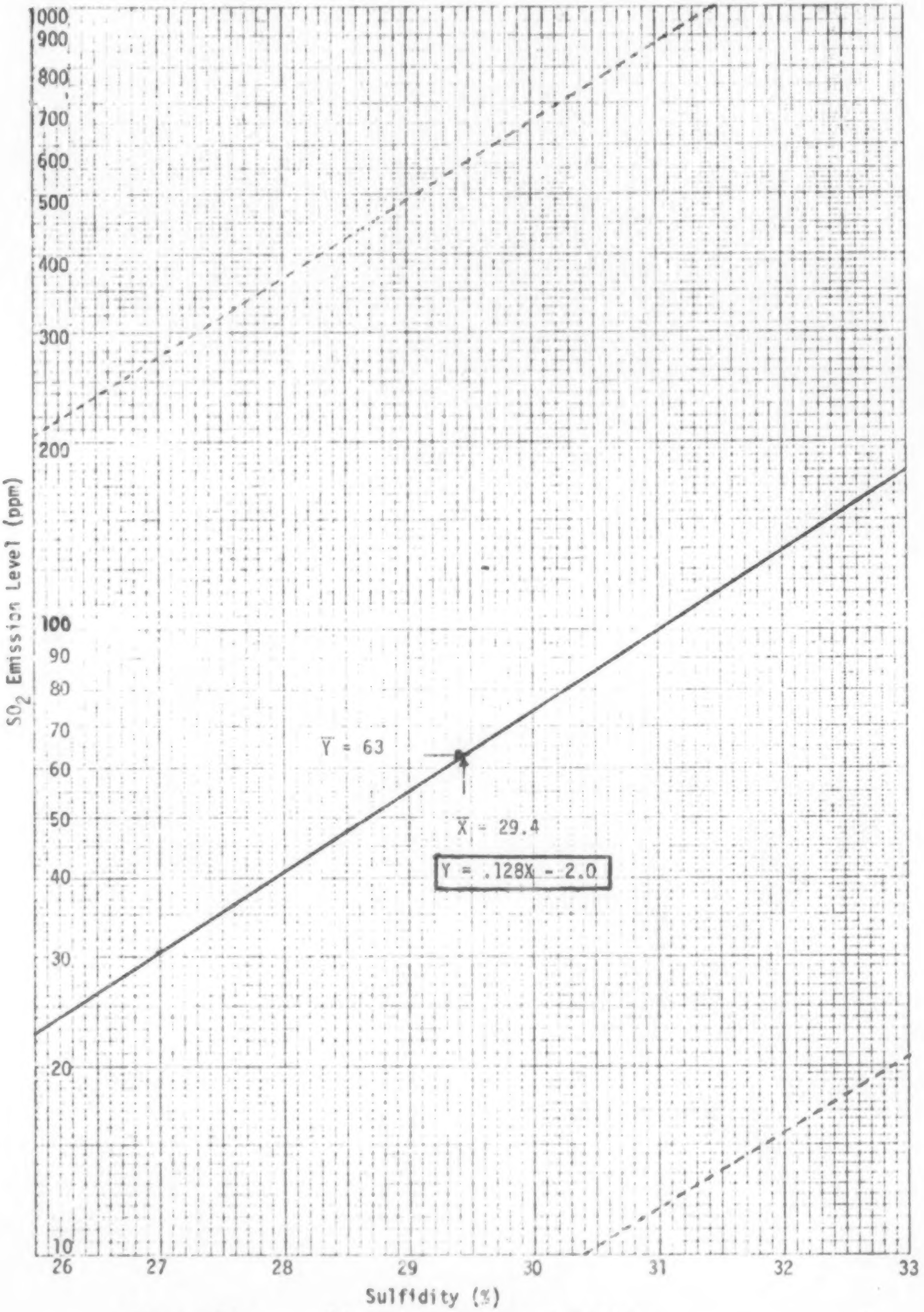


Figure 15 SO_2 Emissions vs. Sulfidity with 95% Confidence Limits for Individual Data Points

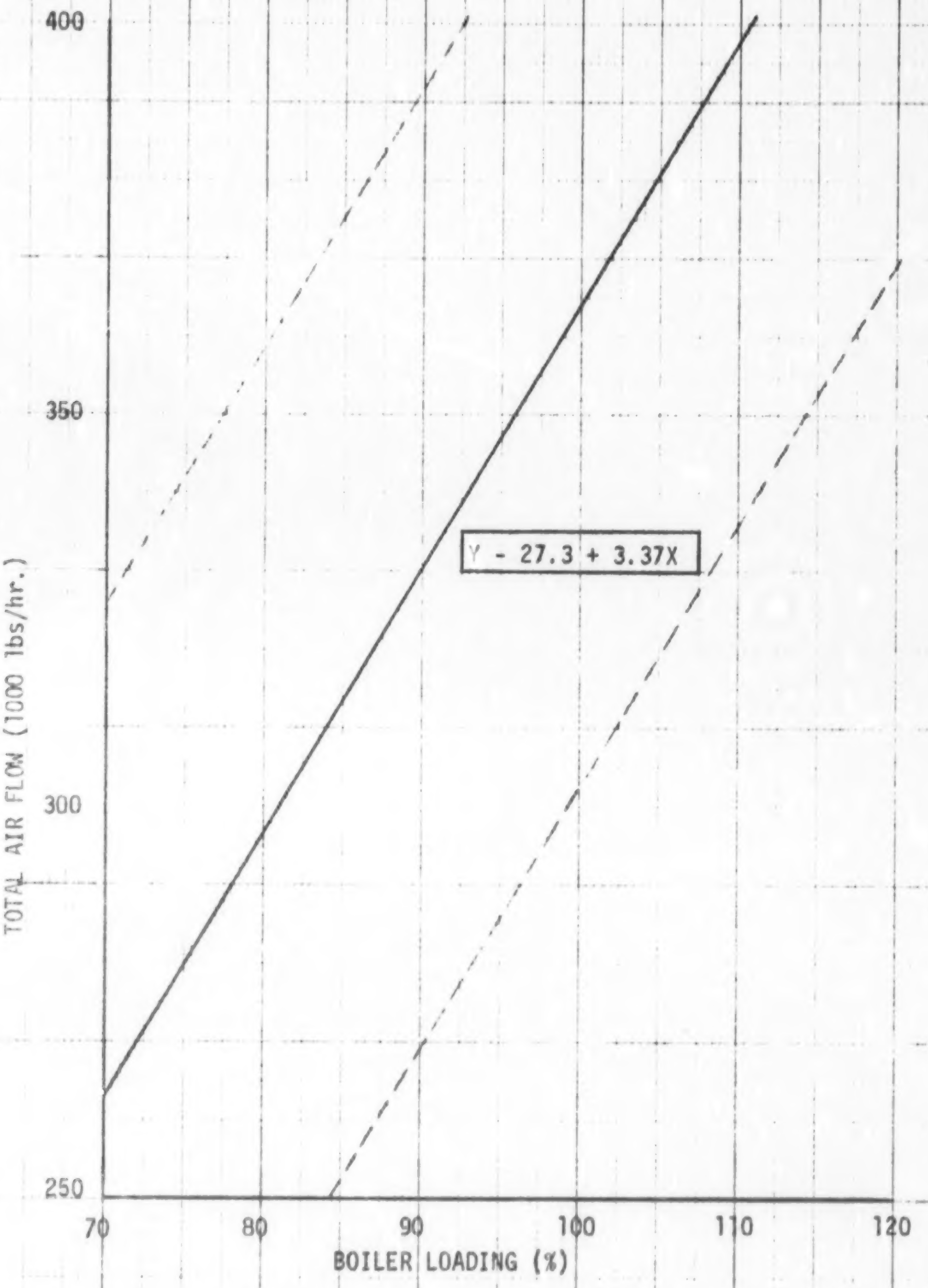


Figure 16 Total Air Flow vs. Boiler Loading
with 95% Confidence Limits for Individual Data Points

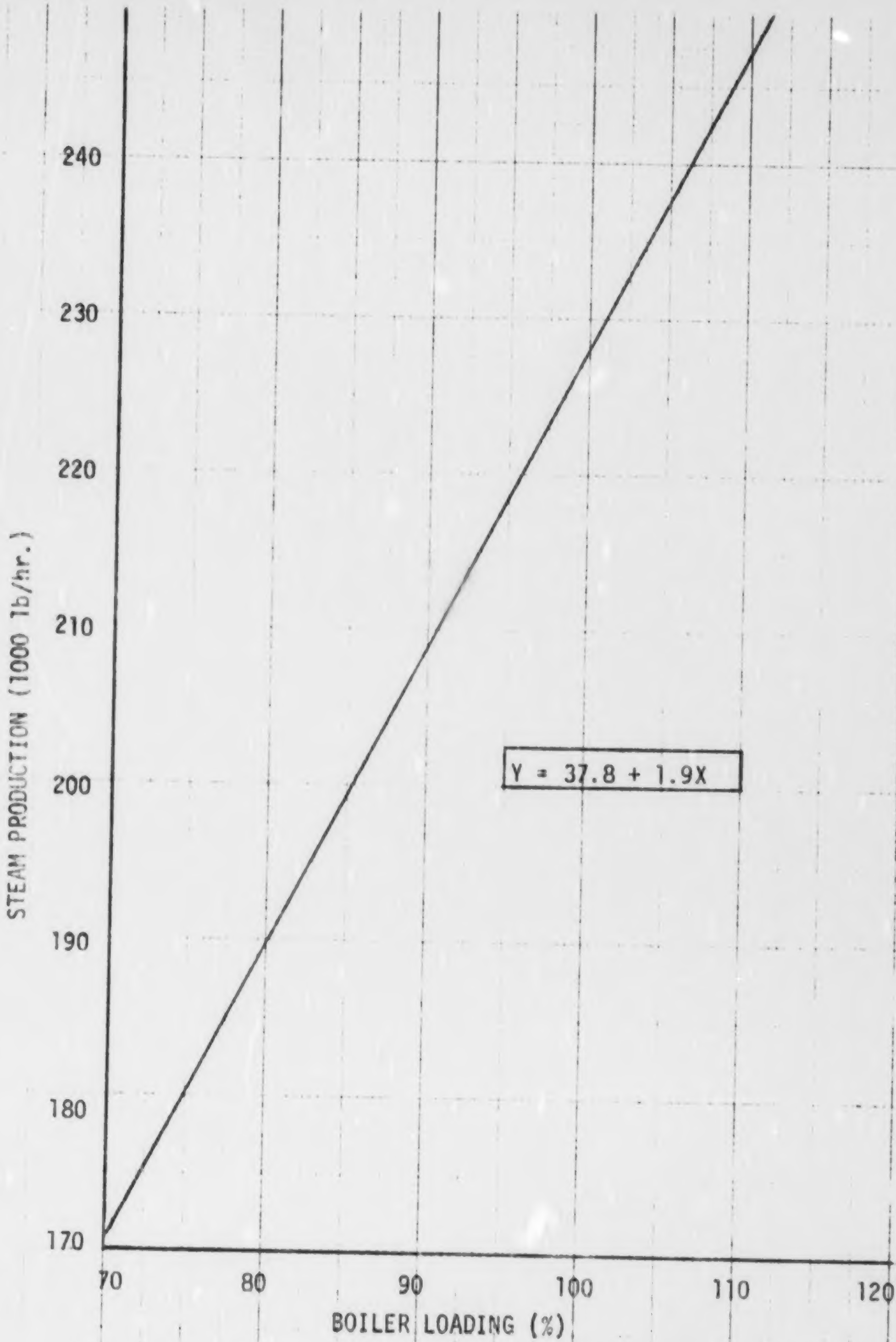


Figure 17 Steam Production vs. Boiler Loading

Figure 18 gives the relationship between precipitator collection efficiency and precipitator inlet gas volume developed from an analysis of all sets of data collected. This regression analysis resembles very closely the expected performance curve developed by the manufacturer for the No. 3 electrostatic precipitator. The design data for this unit indicates a 99.125% collection efficiency at a gas volume of 207,000 ACFM. The result obtained from the statistical analysis of all data is 98.92%, which agrees quite well with the design figure considering the wide range of operating conditions investigated.

ANALYSIS OF SUB-RELATIONSHIPS (INTERACTION OF OPERATING VARIABLES)

The stepwise analysis of the cumulative significance of the various independent variables on each dependent variable indicated that in the case of both TRS and SO_2 emissions, the second most significant variable was sufficiently important to warrant a regression analysis of subsets.

In order to determine the sub-relationships of the variables being examined, the regression coefficient (slope) of the regression line for each subset of data was compared with the slope of the overall regression line. If there is a significant difference (at a 95% confidence level) between the slopes, it was concluded that the slope of the subset data is not the same as the slope of the universe regression line for all data as estimated by the sample line and its confidence limits. If the difference in slopes was not significant, the value of the dependent variable (Y) in the subset of the mean point ($\bar{X}$) of the independent variable was compared with the confidence limits for the Y intercept of the overall regression line computed at the mean ($\bar{X}$). If that difference is statistically significant, it was concluded that the Y intercepts are not the same and a family of curves exist.

For the TRS Emission vs. Excess Oxygen relationship, subsets of data for three target sulfidity levels were analyzed. The results are indicated in Figure 19 and summarized in Appendix F. Only the analysis of normal sulfidity data compared favorably with the slope and intercept limits for the overall regression line. Both the low and high sulfidity data sets showed markedly different slopes and intercepts. This suggests different relationships for all three subsets of sulfidity data. It is interesting to note that although the slopes of the three sulfidity regression lines in Figure 19 are very different, the low and normal sulfidity lines converge in the normal excess oxygen range of 2.0 to 3.0%. This bears out experience and observations at the mill that very little difference in TRS emissions is noted until higher sulfidity liquor is being processed. At an excess oxygen level of 2.5%, low sulfidity TRS emissions average 6 ppm; those for normal sulfidity average 7 ppm; those for high sulfidity shift appreciably up to 18 ppm. This difference in TRS levels was also revealed in the cumulative percentage plot of daily average TRS data (Figure 7) discussed in Section XII of this report. There we found that the data curves fo low and normal sulfidity values were essentially the same, this plot indicating a TRS average of 7 ppm at the 50% cumulative data

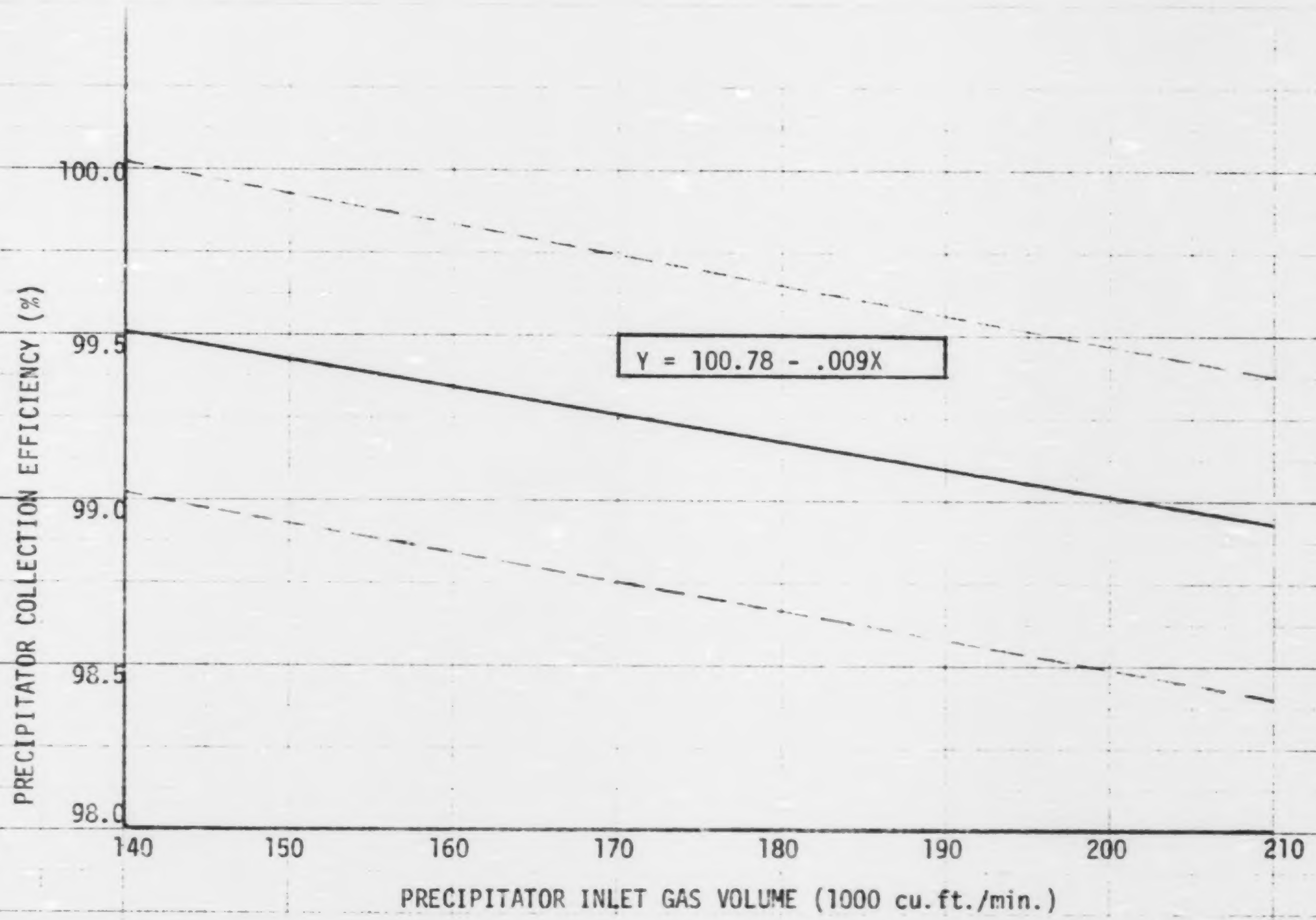


Figure 18 Precipitator Collection Efficiency vs. Precipitator Inlet Gas Volume with 95% Confidence Limits for Individual Data Points

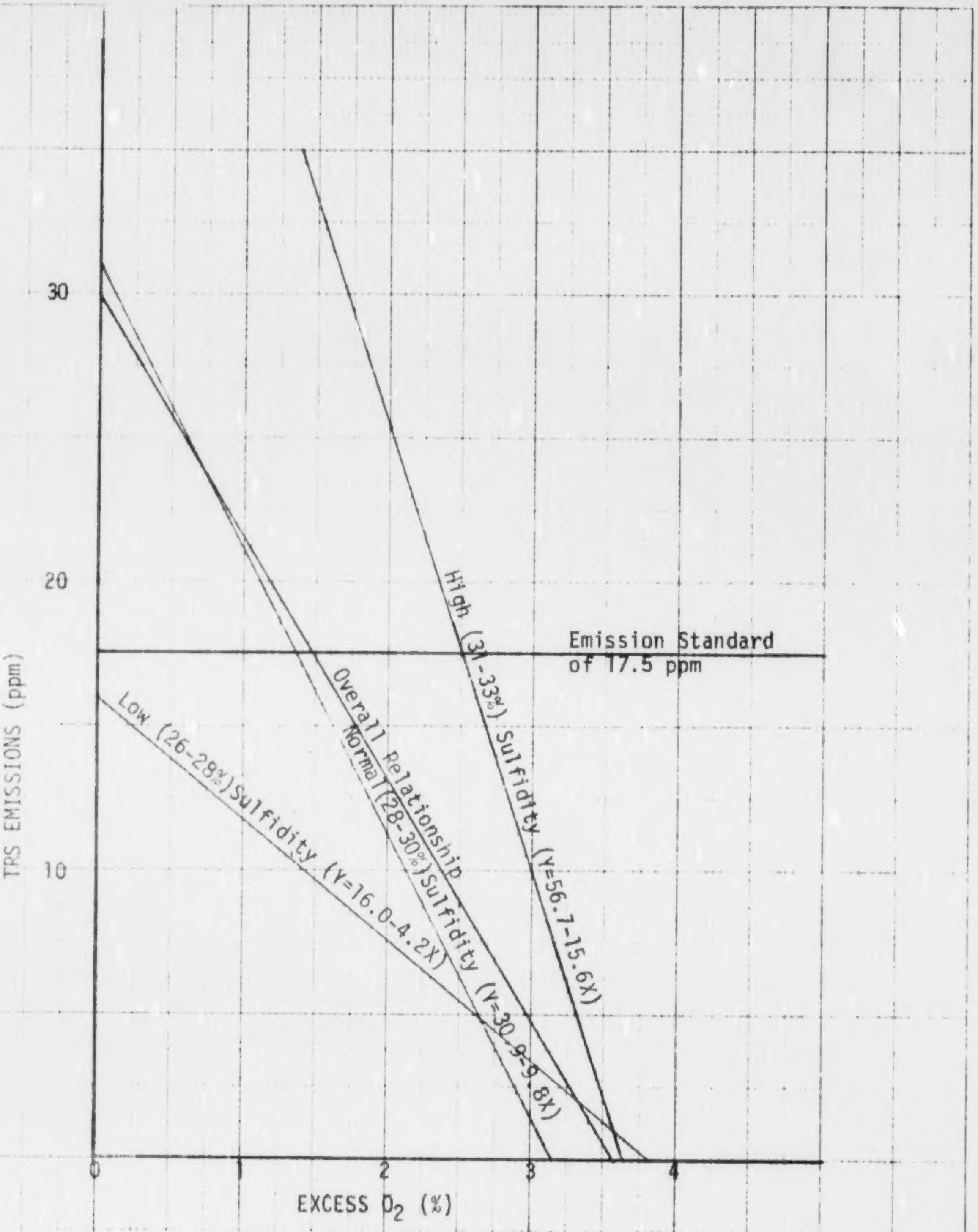


Figure 19 TRS Emission vs. Excess Oxygen
Overall Relationship and Sub-relationships for Sulfidity

level. The average TRS value obtained from the high sulfidity curve was 13 ppm at the same 50% data level.

For the SO_2 Emission vs. Sulfidity relationship, subsets of data for three different excess oxygen levels were analyzed since this variable was the second most significant one revealed in the correlation matrix analysis. Even though excess oxygen contributed 30% to the overall regression line for two independent variables, the regression coefficients (slopes) for all excess oxygen subsets are found to be within the confidence limits of the regression coefficient of the overall data. The intercepts for the subsets also fall within the 95% confidence limits for the overall intercept limits. These results suggest that the overall regression line describes the relationship between SO_2 emissions and sulfidity for all excess oxygen conditions. This is not too surprising in view of the wide range of SO_2 values indicated by the 95% confidence limits established in Figure 15. The regression lines for low and normal excess oxygen subsets are illustrated in Figure 20. The regression analysis for high excess oxygen was not statistically significant (low "F" value obtained), probably due to small amount of data available for analysis in the 3.10% to 4.00% excess oxygen range.

An analysis of subsets was also made for the Total Air Flow vs. Boiler Loading relationship described earlier in order to ascertain the effect of air distribution on this relationship. Although the regression coefficients for all three subsets fall within the overall regression coefficient limits, the intercepts (Y) at the mean point ($\overline{X}$) are significantly different. This indicates a family of curves (regression lines) that are illustrated in Figure 21. These results support the observation that more total air was required to maintain proper combustion conditions in the recovery boiler when primary air was low (35%). The increase in total air flow required over "normal" primary air (45%) was 16,000 lbs/hr., almost the same incremental increase in air flow required when increasing the level of excess oxygen from 1.5% to 2.5% for the normal (45/40/15) air distribution condition.

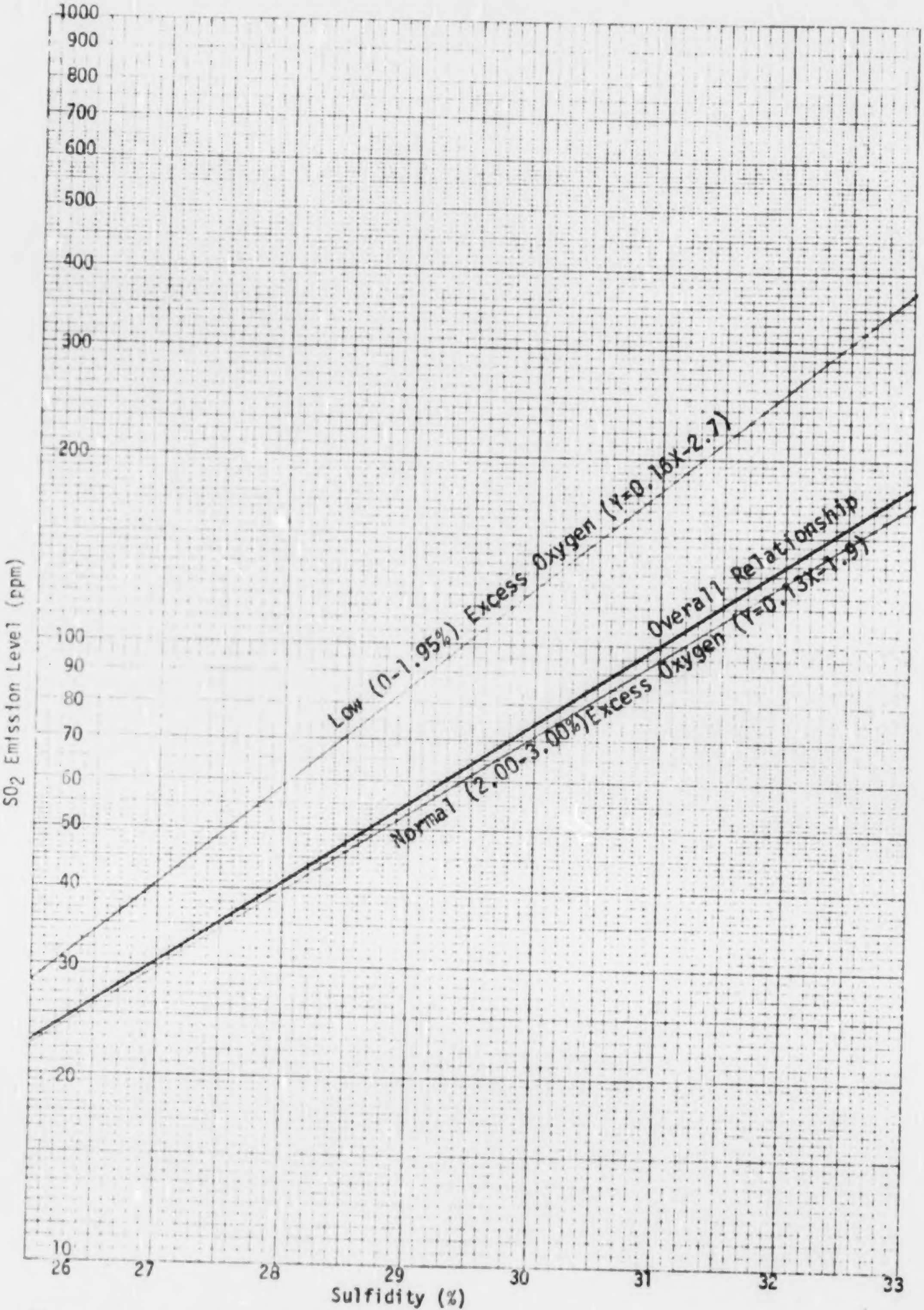


Figure 20 SO_2 Emissions vs. Sulfidity
Overall Relationship and Sub-relationships for Excess O_2 (%)

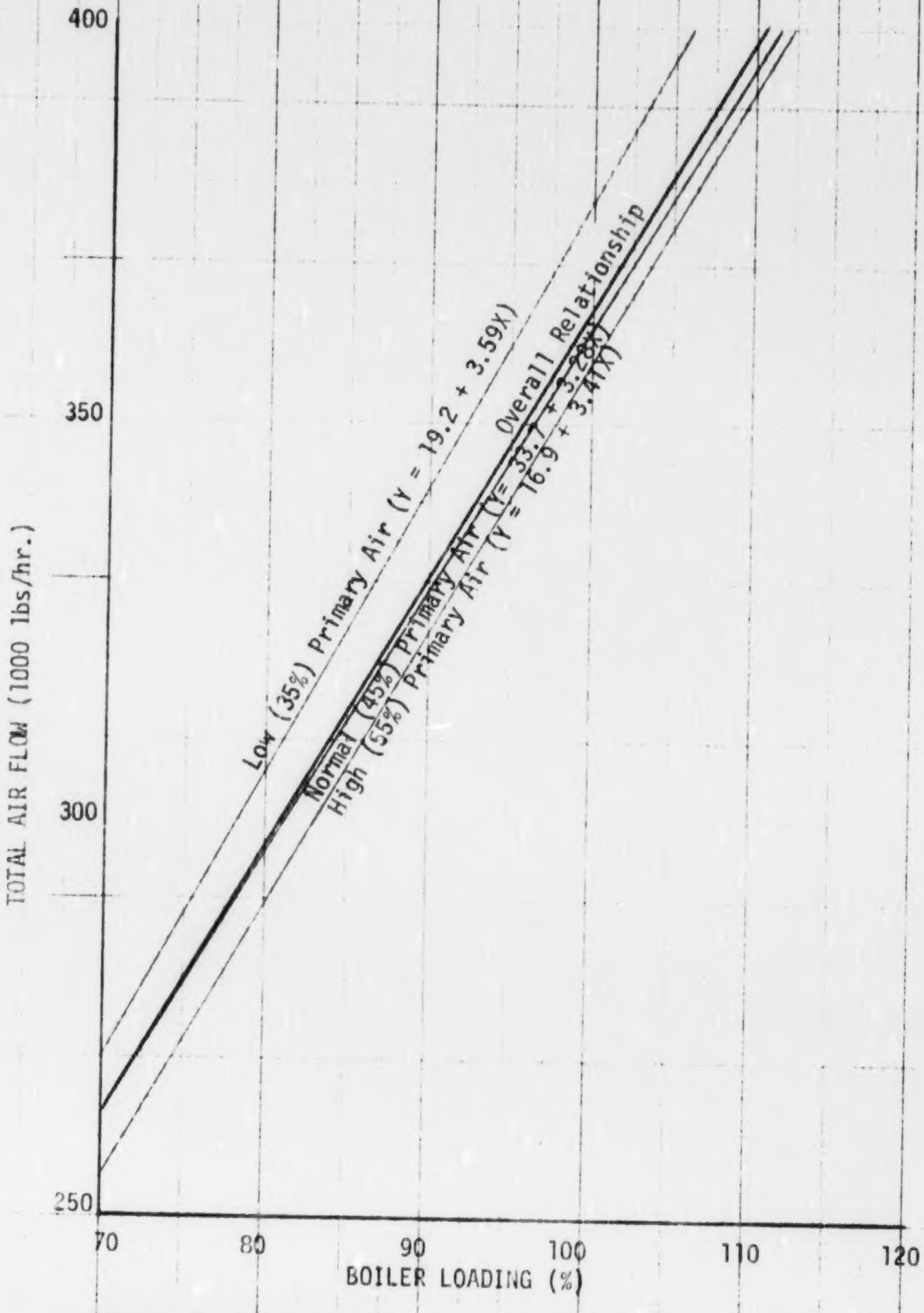


Figure 21 Total Air Flow vs. Boiler Loading
Overall Relationship and Sub-relationships
for Air Distribution

SECTION XV

EXPANDED TEST PROGRAM

INTRODUCTION

The basic EPA test program carried out during the period March-October, 1973 was intended to establish the effect of major variables such as boiler loading, sulfidity level, air distribution combinations, and excess oxygen on boiler emissions (TRS, SO_2, and particulate). During the course of this testing program, it became apparent that other operating variables were also having some effect on emissions.

An additional month of testing on No. 3 recovery boiler was therefore programmed in order to investigate these additional operating variables felt to be of some significance in overall emission control. These included:

Liquor solids
Liquor temperature
Nozzle size vs. nozzle pressure
Secondary windbox pressure
Tertiary windbox pressure
Salt cake addition

The data sheets for this additional test program will be found in Appendix H.

PLAN OF INVESTIGATION

The expanded program was carried out during January and February, 1974. In so far as possible, boiler loading, sulfidity, air distribution, and excess oxygen were maintained fairly uniform within normal limits for each of these variables. For the expanded program, only the one operating variable being investigated was varied while all others were held constant. At least two sets of data were taken for each set of conditions investigated; in some cases four sets of data were taken.

Liquor solids at both low (56-58%) and high (64-66%) solids level in the recovery boiler feed liquor were investigated during a four-day test period. All other conditions were fairly stable during this period. Boiler loading ranged from 87% to 102%, sulfidity from 27.4% to 28.9%.

Liquor temperature was lowered from a normal level of 250°F to 220-225°F for a two-day period and four tests were carried out to evaluate noticeable changes in boiler emissions. All other conditions were stable during this period. It was felt that a lower feed liquor temperature might result in a lower smelt bed temperature resulting in some reduction of vaporized sodium. The overall result would then be an increase in SO_2 emissions and a reduction in particulate emissions.

The relationship between nozzle size and nozzle pressure was investigated during three days in November and three days in January. The sulfidity level in November was 30%, that in January was 27-28%. This change in sulfidity level was not purposely made. This investigation was made to determine the relationship between liquor droplet size and emissions.

Low secondary windbox pressure was thought to effect combustion and gaseous emissions of SO_2 and TRS due to the reduction of oxygen admitted at the smelt bed. An increase in emissions was anticipated. Two days of testing were carried out.

Low tertiary windbox pressure was thought to contribute to increased carryover of particulate from the smelt bed, thereby resulting in higher particulate emissions from the boiler. Two days of testing were carried out.

Three different addition rates of salt cake were investigated over a three day period. The reduction of salt cake (Na_2SO_4) to sodium sulfide (Na_2S) is an endothermic(BTU depletion) reaction and should tend to lower the temperature of the smelt bed. The anticipated result would be an increase in SO_2 emissions similar to the situation resulting from a lower liquor temperature.

TEST RESULTS

Low and High Black Liquor Solids

Table 24

INVESTIGATION OF EFFECTS OF LOW AND HIGH BLACK LIQUOR SOLIDS ON RECOVERY BOILER EMISSIONS

	High Liquor Solids					Low Liquor Solids				
Date	1/22/74		1/23/74		Avg.	1/24/74		1/25/74		Avg.
Test No.	1	2	1	2		1	2	1	2	
Sluice Solids(%)	65.5	65.9	64.6	64.7	65.2	57.8	58.3	56.8	61.4	58.6
Nozzle Size	40	40	40	40		40	40	40	40	
Nozzle Pressure(psi)	40	40	40	40		43	43	44	44	
Sulfidity (%)	29	29	29	29	29	27	27	28	28	28
Boiler Loading(%)	102	102	100	99	101	92	91	87	98	92
Excess Oxygen(%)	2.0	2.1	2.3	2.6		3.0	3.2	3.1	1.3	
Boiler Exit(lb/hr.)										
Actual	4599	3252	4090	3817	3940	2961	2749	2378	4226	3071
*Figure 12 Value	4390	4390	4270	4210	4340	3760	3700	3460	4140	3760
Difference	+209	-1138	-180	-393	-400	-799	-951	-1082	+86	-689
Average TRS(ppm)		0.4		NA			0.3		4	
Average SO_2(ppm)		0		NA			6.5		1	

* 95% confidence limits are ± 1272 at 90-100% boiler loading

The actual values obtained for particulate emissions from the boiler have been compared in Table 24 with the values obtained from Figure 12 which gives the overall relationship between boiler exit dust load and boiler loading established from the 126 sets of data collected in the initial test program. The average black liquor solids level for that data was approximately 61.5%. Only two values out of 126 exceeded 65.0% and only eight exceeded 64.0%, meaning that the data variation encountered and the 95% confidence limits of ± 1272 units (± 30% of mean value at 100% boiler loading) derived from the basic test data (see Table 7 in Appendix F) was weighted little by the more extreme (higher) values of black liquor solids investigated in the expanded program.

For this reason it is significant that all of the data points tabulated in Table 24 do fall within the previously established 95% confidence limits. Moreover, most of the new data points, whether high or low solids data, tend to fall below the mean regression line for Figure 12. The conclusion is that the variation in black liquor solids over the range 57% to 66% does not significantly affect the amount of particulates discharged from the recovery boiler in the exit gas stream.

In all cases TRS emissions were at or below four (4) ppm and SO_2 emissions were below seven (7) ppm, both considered satisfactory from a control standpoint.

Black Liquor Feed Temperature

For the expanded test program, black liquor feed liquor temperature was reduced to a level of 220 - 225°F vs. the normal level of 245 - 250°F maintained throughout the earlier test program discussed in SECTION XIII. No abnormal operating problems were encountered as a result of cooler liquor. Emissions did not appear to be affected significantly one way or the other. Using the linear regression line in Figure 12 as a reference, all of the values for particulate emissions obtained from low liquor temperature operating conditions fall within the overall 95% confidence limits shown in Figure 12. Three of the four values deviate less than 100 units from the regression line value at each particular boiler loading condition. The deviation of the average of all four data points from the average regression line value is only 337 (4480-4143), considerably less than the ± 1272 confidence limits.

Because of the relatively low sulfidity conditions (27.0 - 27.4%) maintained for this testing period, both TRS and SO_2 emissions were low despite a relatively low excess oxygen level. TRS values did not exceed 14 ppm which compared favorably with the regression line for this variable shown in Figure 14. SO_2 values were extremely low, never exceeding seven (7) ppm.

Nozzle Size vs. Nozzle Pressure

The purpose of this testing was to determine if TRS, SO_2 and particulate emissions could be varied while maintaining a constant liquor load by using different sized nozzles and pressures. The tests were performed on November 14, 15, 16, 1973, and on January 28, 29, 30, 1974. A basic difference between the two test periods was a higher sulfidity during the November test period, compared to the January test period (30.2% versus 27.2%).

The data is summarized below.

Table 25

NOZZLE SIZE AND PRESSURE VERSUS EMISSIONS

Nozzle Size	32	36	36	38	40	40	Overall Averages	
Nozzle Pressure(psi)	48	45	39	42	35	35		
Sluice Solids(%)	64.6	62.5	63.8	62.5	59.4	63.7		
Salt Cake Addition(lb/min.)	15	45	15	45	45	15	45	15
Sulfidity(%)	28	30	27	31	30	27	30	27
Boiler Loading(%)	90	101	91	91	89	89	94	90
Excess Oxygen(%)	3.0	2.5	2.2	1.8	2.0	2.8	2.1	2.7
Boiler Exit(lb/hr.)	3963	3669	4002	2603	3511	3597	3261	3854
TRS (ppm)	1	15	2	25	12	0	17	1
SO_2(ppm)	1	74	0	119	130	3	108	1

A review of the emission data tabulated above does not reveal any particular trends as nozzle size and pressure vary. In the earlier EPA test program nozzle pressure remained fairly constant at 38-40 psi and nozzle size was varied to accomodate the different liquor flows established (i.e., boiler loading condition).

All of the particulate data collected during the period of nozzle size and pressure investigation fell within the 95% confidence limits for individual data points shown in Figure 12 except the one low value of 1773 lb/hr. obtained on November 15 when a nozzle size of 38 (nozzle pressure of 42) was in effect. The precipitator efficiency calculated from this data was also low, casting additional suspicion on the particulate results obtained at that time.

For a particular sulfidity level (either high or low), TRS and SO_2 emissions are not significantly affected by a change in nozzle pressure. There is a significant shift in average SO_2 emissions (from 1 to 108) when the sulfidity level shifts from 27% to 30%, bearing out the conclusions reached in the basic EPA testing program carried out in 1973.

TRS emissions also were higher for the high sulfidity periods. Excess oxygen levels were also lower during these periods which would also tend to increase TRS emissions. All TRS and SO_2 data fall within the 95% confidence limits established earlier and shown in Figures 14 and 15 respectively.

Low Secondary Windbox Pressure

The windbox pressure during the two tests performed on February 7, 1974 was lowered from the normal 5-7" H_2O to about 4" H_2O. There were no appreciable changes in any of the emissions.

Low Tertiary Windbox Pressure

The windbox pressure during the four tests performed on February 4 and 5, 1974 was lowered from the normal +8" H_2O to 4" H_2O. There were no appreciable changes in any of the emissions.

Low Secondary and Tertiary Windbox Pressure

This condition was inadvertently present on February 7, 1974, and was not a part of the original work plan. Both the secondary and tertiary windbox pressures were around 4" H_2O. The SO_2 emissions did increase slightly during the two tests conducted (15-25 ppm) as compared with the very low level (1-5 ppm) maintained the rest of the week. The reason for this increase is believed due to the lack of turbulence in the furnace above the bed. This may lead to the channeling of portions of the gases, blocking the intimate mixing of vaporized sodium and SO_2. Statistically, there is very little difference in SO_2 emissions of five and 25 ppm when the broad 95% confidence limits are examined.

Salt Cake Addition

This testing was conducted during the week of February 10. It was expected that the boiler exit particulate and SO_2 emissions would increase with an increase in Na_2SO_4 addition. The three feed rates of salt cake established were 25, 50, and 75 lbs/min. During all three test days, particulate emissions did not appreciably change. The highest level of SO_2 (55 ppm) was obtained during the highest addition rate period but this was well within the normal range of SO_2 established in the earlier test program. The tentative conclusion reached is that sulfidity and not the amount of salt cake addition per se primarily affects the level of SO_2 emissions. This is also borne out by the data presented earlier in Table 25 where 15 lb/hr. of salt cake was being added during the low sulfidity periods of investigation and 45 lb/hr. during the higher sulfidity periods. During the basic EPA testing program the typical salt cake addition rate was 40-50 lb/hr.

SECTION XVI

MISCELLANEOUS TESTING STUDIES

ENVIRONMENTAL SCIENCE AND ENGINEERING, INC. STUDIES

Comparison of Barton Titrator and Gas Chromatograph Results for TRS and SO_2 Emissions

Environmental Science and Engineering, Inc. entered into a 13-week contract with EPA to carry out some specific testing studies to complement those being carried out by Hoerner Waldorf on No. 3 recovery system. One of these studies involved monitoring sulfur gas emissions at the stack using a gas chromatograph in order to compare the results obtained with the usual Barton titrator data taken. Gas chromotography testing began on March 21, 1973. Initially the procedure involved a one-hour test period with gas injection to the cell every five minutes. This was later increased to a two-hour test period. The only TRS compound identified by the GC was H_2S. Poor agreement between the Barton titrator and gas chromotograph was noted for both TRS and SO_2 readings during the first three weeks of testing (identified as Period 1 in Table 26). Following modifications made on April 16 to minimize differences between the two sampling systems, better agreement was obtained. For the test period 5/7 - 6/15/73 inclusive, (identified as Period 2 in Table 26) average TRS results were 1.7 ppm for the Barton and 2.3 ppm for the GC for 16 sets of data. The average difference in readings (based on absolute error, E) also decreased appreciably. For this same period the average SO_2 results were 38 ppm for the Barton and 40 ppm for the GC as compared to a difference of 57 vs. 70 for Period 1. The average difference between Barton and GC SO_2 readings based on the calculated absolute error, E, did not improve very much, however. All of this data is summarized in Table 26.

Barton Titrator Accuracy

TRS and SO_2 emission data collected with the Hoerner Waldorf Barton titrator and Environmental Engineering gas chromatograph showed many discrepancies. An investigation to determine the reasons for these discrepancies was conducted by Hoerner Waldorf, Environmental Engineering and NCASI personnel. The investigation was performed by injecting known quantities of H_2S and SO_2 into each sampling system by the motor driven syringe technique. This is the same technique which is used for routine Barton calibration. The major differences between the GC and Barton sampling systems were as follows:

1. The GC had a heated sample line; the Bartons did not.
2. The TRS Barton cell had a potassium biphthalate scrubber for SO_2 removal.
3. Both Barton systems employed one-liter surge tank for condensate knockout, whereas the GC sample line fed directly. Both sampling systems employed a long sample line (50 to 70 feet in length).

Table 26

TRS AND SO_2 EMISSIONS AT NO. 3 RECOVERY STACK

(Comparison of Hoerner Waldorf and Environmental Engineering Data)

Date	Comparison Time Hours	Boiler Loadings(%)	Air Distribution(%)	Excess O_2	TRS AVG.(ppm)		SO_2 AVG.(ppm)		Data Difference (Barton-GC)	
					Barton	GC	Barton	GC	TRS	SO_2
3-21-73	0.75	100	35/50/15	2.3	4.0	14.0	30	69	-10.0	-39
3-22-73	1.08	100	55/30/15	3.5	9.6	2.4	50	29	+ 7.2	+21
3-23-73	0.75	100	55/30/15	2.5	14.8	9.0	82	181	+ 5.8	-99
3-27-73	1.58	75	45/40/15	3.2	3.1	3.6	19	19	- 0.5	0
3-29-73	0.66	75	45/40/15	2.2	3.0	4.7	30	31	- 1.7	- 1
3-30-73	1.00	75	55/30/15	2.2	0.9	6.1	0	1	- 5.2	- 1
4-2-73	0.75	75	35/50/15	2.7	4.8	2.6	10	46	- 2.2	-36
4-4-73	0.42	75	55/30/15	2.2	14.3	3.2	114	99	+11.1	+15
4-11-73	1.00	110	45/40/15	2.5	5.7	1.4	62	57	+ 4.3	+ 5
4-12-73	0.92	110	45/40/15	2.5	9.9	1.7	136	89	+ 8.2	+47
4-13-73	0.92	110	45/40/15	1.0	29.5	5.9	168	116	+23.6	+52
4-16-73	0.92	110	45/40/15	2.4	0.7	1.3	41	101	- 0.6	-60
4-17-73	0.92	110	45/40/15	3.3	1.6	1.4	35	101	+ 0.2	-66
4-18-73	0.92	110	35/50/15	2.0	0.6	2.3	12	34	- 1.7	-22
			Period 1 Average		7.3	4.3	56.8	70	* 8.4	*44
5-7-73	0.75	100	35/50/15	2.1	2.5	2.9	20	10	- 0.4	+10
5-22-73	1.00	100	45/40/15	3.0	0.4	1.1	139	57	- 0.7	+82
5-23-73	1.50	100	45/40/15	3.7	0.4	0.9	7	69	- 0.5	-62
5-23-73	1.17	100	35/50/15	4.2	0.7	0.9	12	79	- 0.2	-67
5-25-73	1.67	Fluctuating Conditions			0.7	0.9	4	30	- 0.2	-26
5-30-73	1.17	75	40/40/15	2.9	4.6	1.0	77	40	+ 3.6	+37
5-31-73	1.17	100	35/50/15	1.4	6.0	1.3	79	51	+ 4.7	+28
6-4-72	1.92	100	35/50/15	2.9	1.4	1.7	62	74	- 0.3	-12
6-6-73	1.58	100	45/40/15	3.0	2.0	3.4	79	91	- 1.4	-12
6-7-73	1.50	100	45/40/15	3.0	0.9	1.9	17	29	- 1.0	-12
6-7-73	1.00	100	45/40/15	3.0	5.8	2.7	27	34	+ 3.1	- 7
6-12-73	2.00	100	35/50/15	2.2	0	4.6	11	6	- 4.6	+ 5
6-12-73	0.75	100	35/50/15	2.0	0.9	8.0	71	34	- 7.1	+37
6-13-73	1.08	75	45/40/15	3.0	1.5	2.1	6	4	- 0.6	+ 2
6-14-73	3.08	100	45/40/15	2.3	0	2.3	3	33	- 2.3	-30
6-15-73	1.50	100	45/40/15	2.7	0	1.1	0	6	- 1.1	- 6
			Period 2 Average		1.7	2.3	38.4	40	* 2.8	*36

* Average of mean squares, E, where $E^2 = \sum_i^n \frac{(\text{Barton-GC})_i^2}{N}$

The results of this investigation are summarized in Table 27.

1. Identical concentrations of H_2S introduced directly to each test unit were read 93 percent high by the GC, and seven percent high by the Barton titrator.

2. A concentration of H_2S introduced through the unheated Barton sampling line was read 81 percent low by the GC, and 28 percent low by the Barton titrator.

3. A concentration of H_2S and SO_2 introduced at the stack to the Barton were read 11 percent (average) low by the H_2S Barton, and 81 percent (average) low by the SO_2 Barton.

From these studies it was concluded that some of the difference in test results obtained could be explained by the difference in sampling time interval. The gas chromatograph analyzed instant samples injected every five minutes whereas the Barton analyzed a continuous sample. It was also suspected that the Barton gas sample line might be absorbing SO_2 in the line. It was agreed that Hoerner Waldorf should do further work to verify the accuracy of the Barton titrator.

Since the Barton's 60 foot unheated sample line was a questionable link in the Barton's accuracy, the Bartons were relocated so only a six foot sample line was used. Introduction of known TRS and SO_2 concentrations through the new sample line resulted in 97 percent recovery of injected H_2S, and 101 percent recovery of SO_2, verifying the Barton's accuracy in their new location. The initial conclusion drawn from this investigation was that the long sample line was responsible for the questionable results obtained during earlier testing. However, there did not appear to be any increase in the level of daily emissions indicated by the relocated Bartons. (The initial testing had indicated that an 81 percent increase in SO_2 emissions could be expected). A third Barton titrator was set up in the old Barton location so a comparison could be made of test results obtained simultaneously at both instrument locations during actual boiler operation. For a 24 hour period the average H_2S measured by the relocated Barton was 9.3 ppm, whereas that measured by the Barton in the old location was 9.5 ppm. A similar test was conducted while monitoring SO_2. For a five-hour period the average SO_2 measured by the relocated Barton was 120 ppm, whereas that measured by the Barton in the old locations was 126 ppm. It was concluded that the Barton readings were correct in both locations. The suspected reason for the discrepancies noted during the original comparative testing period is the possibility of error introduction by the spiking method employed. When the sample line was shortened there was a corresponding decrease in the sample volume handled. This reduced the dampening effect with a large sample volume. It is believed that if it were possible to inject a known quantity of H_2S or SO_2 for several hours the dampening effect would be minimum and more accurate comparisons could be made.

Table 27

H_2S AND SO_2 INTERFERENCE TESTS

Sampling Mode	Concentration (ppm)	Instrument Reading		Error (%)	
		Barton (ppm)	GC	Barton	GC
H_2S directly to Barton TRS cell	9.8	8.9	-	- 9.2	
	19.6	17.8	-	- 9.2	
H_2S directly to Barton and GC(simultaneously)	5.4	5.8	10	+ 7.0	+93
H_2S to Barton and GC thru Barton sampling line(simultaneously)	8.6	6.2	1.6	-28.0	-81
H_2S to Barton and GC thru heated GC sampling line(simultaneously)	10.6	8.8	9.2	-17.0	-13
H_2S to Barton TRS cell thru heated GC sampling line(simultaneously)	29.4	29.5	-	0	
	29.1	23.3	-	-20	
	54.0	47.6	-	-12	
SO_2 to Barton SO_2 cell (introduced at stack)	98.0	11.9	-	-88	
	98.4	27.2	-	-73	

The Barton titrators were calibrated about once a week during the test period. For a given cell set at a given instrument range the change in calibration factor reflects the inaccuracies of preparing sample gases and calibration techniques, electronic instability, cell aging, and the influence of changes in ambient temperature and humidity. The titrator is calibrated with H_2S and SO_2 gas. Most calibrations were done on range 10 because this was the primary range used. A few calibrations were also made for range 30.

As a measure of error, the standard deviations of the calibrations were calculated for each combination of cell, range and gas. Sigma values (σ) expressed as a percent of the average value were:

CELL	RANGE	SIGMA VALUE (σ)	
		H_2S	SO_2
TRS	10	11.4%	---
SO_2	10	10.7%	8.8%
SO_2	30	9.7%	10.8%

There is an error of unknown magnitude when a reactive gas concentration in the stack is changing due to the surge and dampening characteristics of the system. The surge capacity is in the sampling lines, scrubber and knockout tanks. The chemical reaction in the cell takes some unknown finite time to achieve equilibrium and the electronic control has a built-in dampening circuit to level out short term peaks and produce a smoother recorder trace. With most of the volumetric surge capacity removed during calibration, it takes from five to ten minutes for the recorder reading to level off after a major change in concentration of the test gas.

Particulate Studies at Boiler Exit

Another of the studies undertaken by Environmental Engineering during their 13-week testing program at Missoula involved particulate emission testing of boiler exit gases ahead of the precipitator using a dry filtration method (EPA train) in order to determine if such a procedure were practical and feasible under conditions of relatively high grain loadings in the gas stream being sampled. Particulate emission testing with the EPA train ahead of the precipitator began on March 28, 1973. Poor agreement with Hoerner Waldorf data was obtained for the first two weeks as seen in Table 28 (Period 1). It soon became apparent that the EPA train was impractical for use in gas streams where the particulate concentration is relatively high (4-8 gr/SDCF). Nozzle plugging, frequent filter changes (every 10-12 minutes), lack of isokinetic conditions due to high gas volume, and an unwieldy equipment train for cleaning and particulate collection all interfered with good, reproducible sampling. A carefully controlled test on April 14 resulted in some modifications made to the Environmental Engineering test procedure. Following that, better agreement was obtained in the joint test data collected as seen for Period 2 in Table 28. An improvement was also

Table 28

PARTICULATE EMISSIONS AT NO. 3 RECOVERY BOILER EXIT
(Comparison of Hoerner Waldorf and Environmental Engineering Data both expressed as grains/SDCF)

Date	Period	Hoerner Waldorf (Wet Scrubber Train)	Env.Engr. (EPA Train)	Data Difference (HW - EE)	
				Absolute	% of HW Data
3/28/73	1	7.45	3.75	- 3.70	-50
3/29/73		7.49	4.65	- 2.84	-38
3/30/73		8.00	5.02	- 2.98	-38
4/ 2/73		6.35	4.77	- 1.58	-25
4/ 3/73		8.31	4.71	- 3.60	-43
4/ 4/73		7.46	5.48	- 1.98	-27
4/14/73		6.09	5.43	- .66	-11
Average		7.31	4.83	$*E^2 = \frac{50.44}{7} = 7.21$	
Range		6.09-8.31	3.75-5.48	$E = 2.7$	
4/17/73	2	6.66	6.55	- .11	- 2
4/17/73		7.48	8.35	+ .87	+12
4/19/73		9.44	8.61	- .83	- 9
4/19/73		7.23	7.81	+ .58	+ 8
4/24/73		8.01	6.01	- 2.00	-25
4/27/73		7.18	7.64	+ .46	+ 6
4/30/73		6.95	7.32	+ .37	+ 5
5/ 1/73		5.89	5.73	- .16	- 2
5/ 4/73		7.73	8.15	+ .42	+ 6
5/ 7/73		8.48	5.17	- 3.31	-39
5/ 8/73		8.01	11.40	+ 3.39	+42
5/ 9/73		6.26	8.30	+ 2.04	+33
5/11/73		7.98	7.61	- .37	- 5
5/29/73		6.13	5.93	- .20	- 3
5/30/73		5.76	4.05	- 1.71	-30
Average		7.28	7.24	$*E^2 = \frac{36.05}{15} = 2.40$	
Range		5.76-9.44	4.05-11.40	$E = 1.5$	

* $E^2 = \sum_i^n \frac{(HW-EE)_i^2}{N}$

noted in the average difference obtained between the two sampling methods based on the calculated absolute error, E (1.5 vs. 2.7).

COMPARISON OF PARTICULATE TEST RESULTS OBTAINED AT STACK WITH EPA TRAIN AND ALUNDUM THIMBLE METHOD

All of the stack sampling for particulate carried out prior to the EPA testing program (begun in March 1972) was based on the alundum thimble method which has always been recognized as an acceptable, official standard method for the determination of particulate concentration in stack gases.

The alundum thimble sampling train consists of a stainless steel nozzle, thimble holder, and probe, followed by a wet scrubber and mist trap. The thimble was sintered alundum, porosity RA-98. A Sprague dry gas meter and a vacuum pump completed the train, with rubber vacuum tubing interconnecting the various pieces of equipment.

For the EPA testing program the EPA sampling train was recommended and therefore it was the only one used for the duration of the entire study carried out during 1972-1973. The details of the EPA test method are described in Appendix C.

In both test methods, stack moisture is determined by measuring the condensate collected during a test. Both methods also call for the overnight drying of the dry particulate catch to remove any moisture. The major difference between the two test methods concerns the treatment of the washdown and scrubber solutions. For the EPA test, the front half (all components before the scrubbers) is washed down and the washings oven dried, with the dried material from the washings added to the filter catch. With the alundum thimble, the washings are mixed with the scrubber water, brought to a specific volume, and then analyzed for sodium on a Coleman flame photometer. This sodium is then converted to equivalent Na_2SO_4 and added to the thimble catch.

Seven simultaneous EPA-alundum thimble comparison tests were conducted to determine if a meaningful relationship could be established between the two sampling trains. With this correlation established, Hoerner Waldorf's earlier data (1969-1971) could be better compared to the more recent data collected with the EPA train. The results of these tests are shown in Table 29. In each of the tests, the EPA train yielded higher grain loadings than the alundum thimble method. The average difference was 0.0131 gr/SDCF.

Table 29

PARTICULATE STACK EMISSIONS
(Comparison of Alundum Thimble vs. EPA Train)

Date	Alundum Thimble (gr/SDCF)	EPA Train (gr/SDCF)	Difference (EPA-AT)
12/10/73	0.0240	0.0439	+ 0.0199
12/12/73	0.0482	0.0610	+ 0.0128
	0.0393	0.0488	+ 0.0095
12/13/73	0.0339	0.0375	+ 0.0036
	0.0324	0.0366	+ 0.0042
12/14/73	0.0373	0.0532	+ 0.0159
	0.0337	0.0593	+ 0.0256
Averages	0.0355	0.0486	+ 0.0131

The use of this average difference (0.0131 gr/SDCF) for comparing grain loadings determined with the EPA train to those determined with the alundum thimble is not recommended, however, since the majority of earlier grain loadings were in a higher range. The majority of the earlier alundum thimble tests were conducted before high (over 95%) precipitator efficiencies were obtained. The earlier stack grain loadings were much higher (in the range of 0.080 to 0.510 gr/SDCF). It would appear that had the EPA train been used for all particulate testing during 1971-1972, the grain loadings would have been even higher than those obtained using the alundum method.

SECTION XVII

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DESIGN PARAMETERS FOR THE MAJOR COMPONENTS OF THE SYSTEM

1. No.3 Recovery Boiler (Babcock and Wilcox unit erected in 1966)

   Nominal Capacity - 470 TPD (based on 3000 lb dry solids per pulp ton)

   Design Loading - 1,400,000 lbs of black liquor solids per day at 6600 BTU/lb (equivalent to 1,418,000 lbs of solids at Missoula with average liquor BTU content of 6515 BTU/lb)
   Recovery Building Dimensions - 60' x 77' x 126'
   Dust Load (max.) from Boiler at Design Load = 8.0 gr/SDCF

   Steam Production (max) - 235,000 lb/hr at 750°F and 600 psi based on feedwater temperature of 275°F entering economizer

   Total Heating Surface in Boiler - 31,167 sq.ft.
   Heating Surface of Superheater - 7,754 sq.ft.
   Heating Surface of No.1 Economizer- 13,300 sq.ft.

2. No.2 Economizer (Babcock and Wilcox unit)

   Heating Surface - 33,347 sq.ft.
   Exit Gas Temperature - 400 °F

3. Evaporator Concentrator (Unitech unit)

Evaporation Capacity	49,000 lb/hr
Total Heating Surface	10,000 sq.ft.

   Feed Liquor - 163,000 lb/hr at 200°F and 44% TS

   Product Liquor-114,000 lb/hr at 236°F and 63% TS

4. Electrostatic Precipitator (Research-Cottrell unit)

   a. Performance Data

Maximum gas flow	207,000 ACFM (70,000 DSCFM)
Maximum gas temperature	400 °F
Particulate to the Precipitator	8 grains/SDCF
Particulate outlet loading	0.07 grains/SDCF
Guaranteed efficiency	99.125%

Performance Data (continued)

Density of salt cake collected	8 lb/cu.ft.
Net Gas Velocity at rated volume	3.55 FPS
Gas Treatment time at rated volume	7.6 Sec.
Collecting area/volume rate flow	0.338
Migration velocity	7.36 cm/sec.

b. Typical Gas Conditions

H_2O by volume	31%
H_2O by weight	21%
Specific Density of Gas	0.037

c. Physical Characteristics of Precipitator

Walls	Tile-lined concrete
Roof	Concrete
Gas Inlet	Top
Gas Outlet	Top
Design Pressure (internal)	20" H_2O
Number of chambers (units)	2(parallel units)
Number of Electrical Sections in series per chamber	3
Number of collecting plates per section	26
Number of ducts (gas passages)per unit	27
Size of each duct	9" x 24' x 27'
Dust Removal System	Drag Bottom Conveyor (2 drag chains per chamber parallel to gas flow) Screw Conveyor (12" dia.x12" pitch)
Collecting Electrodes	Solid Steel Plates
Total Collecting Area	70,000 sq.ft.
Total Electrode Length	46,600 feet

d. Electrical Components

Discharge Electrodes	Series of vertical wires, suspended midway between the collecting electrode plates. (.109" diameter bessemer steel with coppered surface)
Collecting Plate Rappers,	
Inlet Section	P-160 Eriez electromagnetic Total 12 (6 each for North side and South side chamber)
Center Section	P-150 Eriez electromagnetic Total 12 (6 each in North side and South side chamber)
Outlet Section	P-150 Eriez electromagnetic Total 12(6 each in North side and South side chamber)
Inlet Distribution Plate Rappers	
Horizontal Units	P-150 Eriez electromagnetic (1 each in both North and South side chambers)
Discharge Wire Rappers	P-160 Eriez electromagnetic Total 12 (6 for North chamber and 6 for South chamber, 2 per electrical section)
Rapping Duration	Variable, from 0.1 to 6 seconds each vibrator
Rapping Intensity	Variable
Power Supply	460 volts 4 amps, 1 phase, 60 cycle
Transformer-Rectifier Units	Total of four
Inlet Field (Section) T-R	One 48 KVA, 50 KV (RMS) 750 ma
Center Field (Section) T-R	One 96 KVA, 50 KV (RMS) 1500 ma
Outlet Field (Section) T-R	Two 64 KVA, 50 KV (RMS) 1000 ma

APPENDIX B

TRS AND SO_2 CALCULATIONS

Two separate Barton titrators were used for the determination of TRS and SO_2 concentrations. One Barton measured and recorded the total sulfur gases present in the stack sample. The other Barton measured the TRS concentration after the SO_2 in the sample gas had absorbed in a potassium acid phthalate scrubber. The TRS value was recorded on the same chart as the total sulfur gas reading from the other Barton. The recording pen for TRS lags the other pen by about 10 minutes on the chart to allow freedom of pen movement.

A continuous record of both TRS and SO_2 were obtained from this two-pen recorder. Examples of typical charts for three different sulfidity levels are shown in Figures 1, 2, and 3. Table 1 summarizes the various factors used in the calculation of TRS and SO_2 values from the chart data. A sample calculation using the chart data of Figure 3 is presented. In all cases 15-minute data points are used in the averaging of data. These data points taken from Figure 3 are tabulated in Table 1. The average for the No. 1 Barton Chart (TRS + SO_2) is 52.3. Using the appropriate factors, the SO_2 concentration is calculated to be 440 ppm (for range 30). The average for the No. 2 Barton Chart is 6.8, calculated to be 5 ppm TRS (for range 10).

All of the TRS and SO_2 data compiled during the course of this testing program was developed in the same manner.

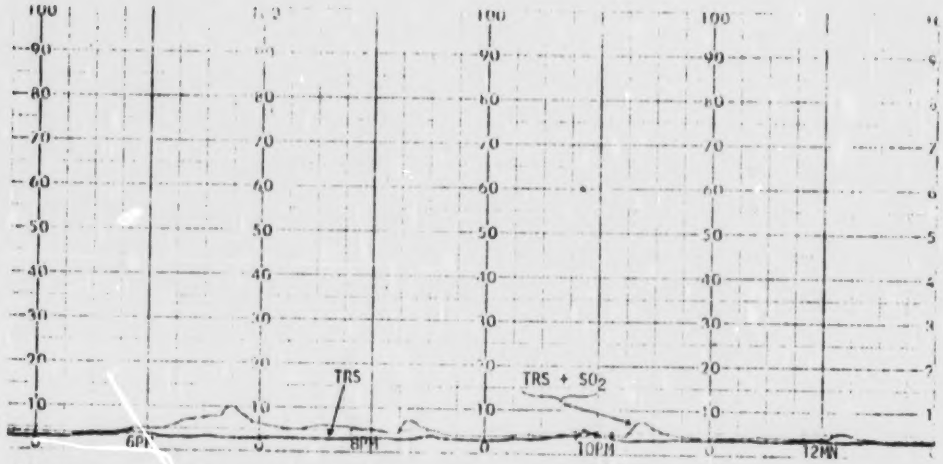


Figure 1 TRS and SO_2 Charts for 28% Sulfidity

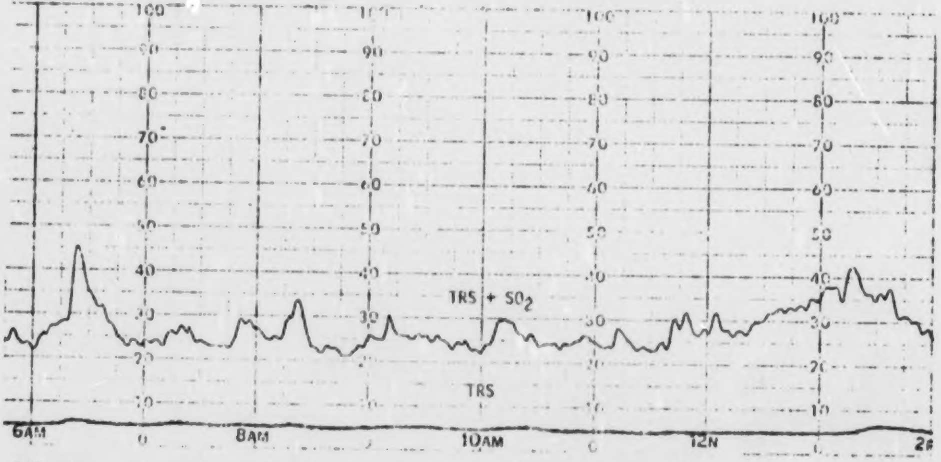


Figure 2 TRS and SO_2 Charts for 29% Sulfidity

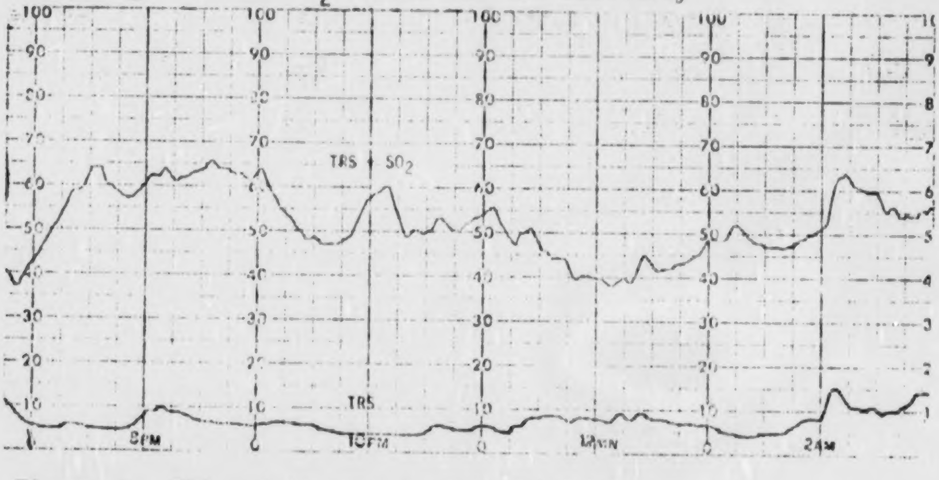


Figure 3 TRS and SO_2 Charts for 32% Sulfidity

Table 1

ANALYSIS OF TRS AND SO_2 CHART DATA

Figure	1	2	3
Date	12/18/73	6/24/73	10/16/73
Time Period	5PM-1AM	6AM-2PM	7PM-3AM
No.1 Barton (Total S Record)			
Base Line Correction	2	2	2
TRS Factor	0.794	0.878	3.01
SO_2 Factor	3.58	3.80	8.95
Range	10	10	30
No.2 Barton (TRS Record)			
Base Line Correction	2	2	2
TRS Factor	0.848	1.020	0.984
Range	10	10	10
SO_2 Analysis (ppm)			
Average	5	82	440
Maximum	21	146	566
Minimum	0	59	312
TRS Analysis (ppm)			
Average	1	3	5
Maximum	3	4	13
Minimum	1	2	2
Sulfidity Average (%)	28.0	29.3	32.3

Clock Time	No.1 Barton Chart	No.2 Barton Chart
7:00PM	43	5
7:15	54	5
7:30	63	5
7:45	59	5
8:00	61	8
8:15	61	9
8:30	63	7
8:45	63	6
9:00	63	6
9:15	54	7
9:30	48	6
9:45	48	4
10:00	58	4
10:15	54	4
10:30	50	4
10:45	50	5
11:00	54	6
11:15	48	5
11:30	46	8
11:45	44	7
12:00MN	40	8
12:15AM	40	9
12:30	42	8
12:45	43	7
1:00	48	7
1:15	52	4
1:30	47	5
1:45	47	6
2:00	51	8
2:15	62	11
2:30	60	10
2:45	54	11
3:00	56	15
Average	52.3	6.8

CALCULATION OF TRS AND SO_2 VALUES

(based on Figure 3 and Table 1 data)

TRS Calculation

To obtain the TRS value from the No. 2 Barton Chart reading, the base line correction is applied and the TRS Factor is applied. We then obtain:

Average TRS value (ppm)

= TRS Factor (No.2 Barton Chart reading - Base Line Correction)

= 0.984 (6.8-2.0)

= 5 ppm

SO_2 Calculation

To obtain the SO_2 value from the No. 1 Barton Chart reading, two corrections are necessary. One is the base line correction, the other is for TRS as measured on this instrument. The TRS factor for No. 1 Barton is applied to the calculated value obtained above in order to do this.

We then obtain:

Average SO_2 value (ppm)

$$= SO_2 \text{ Factor} \left[\text{No. 1 Barton Chart reading - Base Line Correction} - \frac{\text{TRS value}}{\text{TRS Factor (No.1 Chart)}}\right]$$

$$= 8.95 \left(52.3 - 2 - \frac{5}{3.01}\right)$$

$$= 8.95 (52.3 - 2 - 1.7)$$

= 440 ppm

APPENDIX C

PARTICULATE SAMPLING

Particulate sampling was carried out twice a day during the EPA testing problem. Concurrent sampling both at the boiler exit duct and at the stack was accomplished by two testing teams in order to get meaningful data for the determination of precipitator collection efficiencies.

Figure 4 shows the detailed configuration of the various sampling points needed for meaningful particulate dust collection. Also shown are the traverse points at which flow measurements were made and dust fractions collected. At both sample points a velocity traverse of the duct or stack is made with a calibrated "S" type pitot tube and inclined manometer. The normal sampling time for particulate at each location was 77 minutes, coinciding with one complete IK sootblower cycle.

The details of the testing procedure employed at each sampling location are given in the following sections.

PARTICULATE SAMPLING PROCEDURE AT RECOVERY BOILER EXIT

Equipment

The sample train used for particulate testing at the boiler exit is illustrated in Figure 4. The probe is 1/2" stainless steel tubing, with an inside diameter of 3/8". The first scrubber-condenser is a 2 liter Florence flask, fitted with a glass bubble tube. The bubble tube is drawn out to a nozzle tip and positioned within 1/4 inch of the flask bottom to take advantage of impingement separation. The second and third scrubbers are commercial Greenburg-Smith impingers, the first with a standard impinger tip and the second with a straight tube. The mist trap consists of moist fiberglass wool, packed in a Gooch crucible to remove any carry over from the scrubbers and to act as a final filter in the system.

The meter is a Sprague dry gas meter, with totalizing dials to 999.99 cubic feet. Calibration is checked periodically with a fixed orifice calibrator. The vacuum pump has a free air capacity of 7 CFM. The flow through the sample train is adjusted by regulating the bleed valve at the pump inlet.

Rubber vacuum tubing is used to connect the various pieces of equipment.

Procedure

1000 ml of distilled water are measured out and distributed to the three scrubbers, reserving about 100 ml for washing the probe into the condensate jar if any plugging occurs. A wad of fiberglass is placed in the crucible of the mist trap and the vacuum hoses connected.

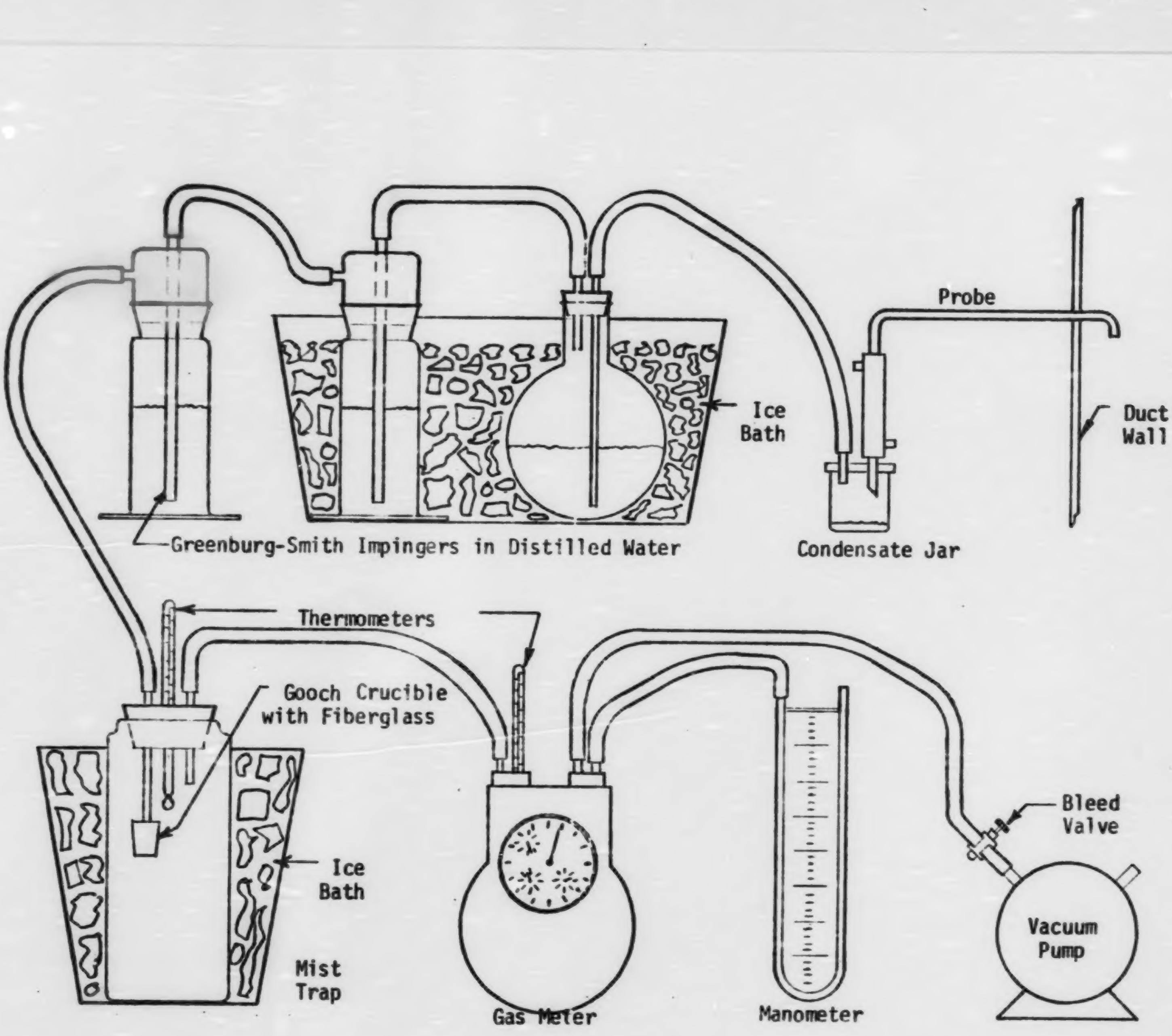

Probe
Duct Wall
Ice Bath
Condensate Jar
Greenburg-Smith Impingers in Distilled Water
Thermometers
Gooch Crucible with Fiberglass
Ice Bath
Mist Trap
Gas Meter
Manometer
Bleed Valve
Vacuum Pump

Figure 4 Hoerner Waldorf particulate sampling train used for boiler exit sampling

The system is checked for leaks by sealing the nozzle tip, drawing a vacuum of at least 10 inches of Mercury and pinching off the hose between the gas meter and vacuum pump. The system is leak free when no bubbles are seen in the scrubber, the gas meter does not move, and the vacuum does not drop perceptibly in one minute.

The duct area is divided into 10 equal rectangles with a sample point located at the center of each rectangle. (See Figure 5).

A velocity traverse is made with a calibrated "S" type pitot tube and inclined manometer. Velocities are read off the calibration chart and corrected for actual gas density. Stack temperature and pressure are measured, but for the preliminary figures, the moisture and gas analysis are assumed from previous tests. From the point velocities, metering rates are calculated to give isokinetic flow at the nozzle tip. (See Table 2).

The probe is inserted into the stack with the nozzle located at the first point, and turned to face upstream. At the same time, the vacuum pump is turned on and the meter flow adjusted to establish isokinetic flow at the nozzle. Each point is sampled for the same length of time (7 minutes). The probe is moved from point to point at each port, without stopping the sample flow. Sampling is stopped when changing ports. During each test, the temperature and vacuum at the meter and the temperature at the mist trap are recorded periodically. (See Table 3).

When sampling is complete, the probe is first rinsed with any remaining water previously reserved from the measured liter. All water in the system is combined and measured. Subtracting the original 100 ml gives the amount of collected condensate. The sample train is washed three times with distilled water. The washings are added to the sample liquid and the whole made up to volume in a volumetric flask (2000 ml).

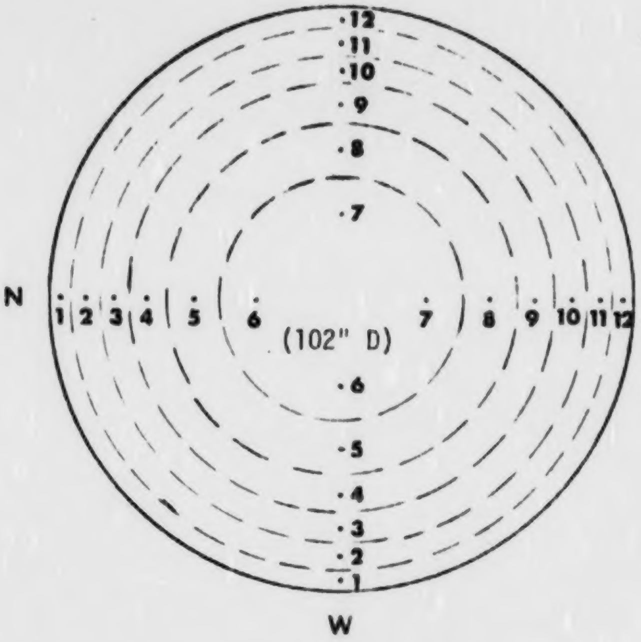
The liquid is analyzed on the Coleman flame photometer for sodium and the concentration multiplied by the total volume gives the total weight of sodium sulfate collected.

The total gas volume measured at the gas meter is corrected to dry standard conditions of 70°F and 29.92 inches of Mercury. The total catch divided by the corrected gas flow sampled gives the dust loading. This is reported as grains of dust per dry standard cubic foot of gas.

The amount of collected condensate is used to determine the moisture in the flue gas and the gas density is corrected for temperature, pressure and moisture. The stack velocity is then corrected for actual gas density at stack conditions and the total gas flow calculated.

The total flow is corrected to dry standard conditions, and by multiplying by the dust loading, the total weight of dust lost is calculated.

Sample calculations follow,


12
11
10
9
8
7
N
1 2 3 4 5 6
7 8 9 10 11 12
(102" D)
6
5
4
3
2
1
W

Stack Sampling Points

Boiler Exit Sampling Points

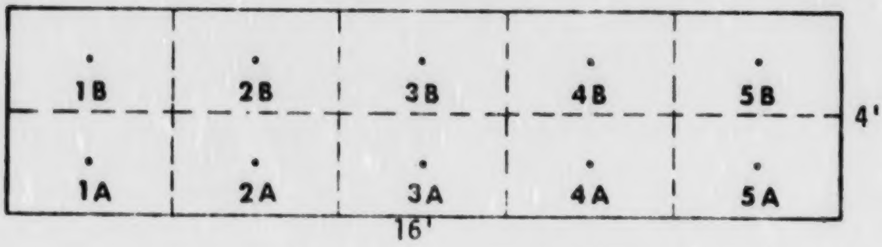

1B
2B
3B
4B
5B
4'
1A
2A
3A
4A
5A
16'

Figure 5 Configuration of boiler exit and stack sampling points

Table 2

DETERMINATION OF AVERAGE GAS VELOCITY IN DUCT (V_c)

DATE	October 24, 1973	DUCT DIMENSIONS	4'x16'=64.0 ft^2(A)
SAMPLE STATION	No.3 Boiler Exit	DUCT TEMPERATURE	595°F (Ts)
PITOT TUBE	A	DUCT PRESSURE	-.40 Hg" (Ps)
CALIBRATION DENSITY	.0730 (ρ_c)	BAROMETER	26.71 Hg" (B)

Traverse Position	Probe Traverse (Inches)	Pitot Tube ΔP (H_2O")	Gas Velocity (Ft./sec.)
1 A	6	.30	33.0
B	18	.35	35.3
C	30	.35	35.3
D	42	.34	34.9
2 A		.22	28.4
B		.23	29.0
C		.28	31.9
D		.17	25.1
3 A		.10	19.6
B		.13	22.0
C		.14	22.8
D		.33	34.5
4 A		.30	33.0
B		.39	37.2
C		.55	43.8
D		.78	51.1
5 A		.42	38.5
B		.45	38.9
C		.64	46.9
D		.81	51.9
		Average	34.66 (V_c)

Table 3

DETERMINATION OF METERED GAS VOLUME (R)

DATE	October 24, 1973	GAS METER NO.	1501352
SAMPLE STATION	No.3 Boiler Exit	CALIBRATION FACTOR	1.02
TESTERS	Wohler and Ball	BAROMETER	26.71 Hg" (B)
TEST NO.	1	DUCT DIMENSIONS	4'x16'=64.0 ft.^{2} (A)

*Traverse Position No.	Inches	Clock Time	Meter Vol. (Cu.ft.)	Meter Temp. (°F.)	Pump Vac. (Hg")	Fume Trap Temp. (°F.)
1A	12	10:45 a.m.	0.00	-	-	-
				98	8.0	52
		10:52	8.00	98	7.6	50
B	36			96	7.8	50
		10:59	15.70	96	7.8	48
2A	12			98	7.0	47
		11:08	22.70	98	7.0	48
B	36			98	7.0	48
		11:15	29.80	98	7.0	48
3A	12			99	5.7	50
		11:23	35.30	100	5.7	48
B	36			98	7.0	48
		11:30	42.30	98	7.0	48
3A	12			100	7.8	48
		11:39	49.20	99	7.8	48
B	36			98	9.6	47
		11:46	58.10	99	10.0	47
5A	12			100	9.4	46
		11:55	67.00	98	9.4	48
B	36			98	9.4	48
		12:02 p.m.	76.00	98		
		Averages	76.00x1.02 = 77.52 ($R_{Corr.}$)	98 (T_m)	7.86 (M)	48 (P_{ft} = .34 Hg")

* See Figure 5

CONVERSION FACTORS AND DEFINITION OF SYMBOLS USED IN CALCULATION OF PARTICULATE LOAD

R = Metered gas volume (as is) expressed in cubic feet (measured)
C = Volume of gas sampled, corrected to dry standard (DS) conditions of 32°F and 29.92 " Hg.
B = Barometric pressure at test station (measured)
M = Meter vacuum (measured)
P_{ft} = Vapor pressure of water at fume trap temperature (measured)
Ps = Pressure in duct (boiler exit) or stack (measured)
ΔP = Pressure drop across orifice outlet (EPA train)
N = Weight of particulate collected expressed in grams
DL = Dust loading expressed as grains per dry standard cubic foot (DSCF)
G_s = Volume of wet gas corrected to standard conditions of temperature and pressure (WSCF)
Hd = Humidity of gas sampled expressed in cu.ft. H_2O/cu.ft.dry gas
Tm = Gas temperature at meter (measured)
Ts = Temperature in duct or stack (sampling point)
W = Condensate collected from gas sample expressed in milliliters or gram - equivalents (measured)
MW = Molecular weight expressed as lb/lb mole
MV = Molecular volume of stack conditions expressed as cu.ft./lb mole
ρ = Gas density at stack conditions expressed as lb/cu.ft.
V_c = Gas velocity measured with Pitot tube expressed as ft./sec.
V = Gas velocity (corrected) in stack expressed as ft./sec.
$\sqrt{e/\rho}$ = Correction factor for actual gas velocity determination
A = Cross-section area of duct or stack expressed in sq.ft.
Q_1 = Total volumetric gas flow expressed as cu.ft./min.
Q^1 = Total volumetric gas flow corrected to dry standard conditions
E = Precipitator Collection Efficiency expressed as percentage
Dry Gas Average Weight = 30.687 lb.(based on several Orsat analyses)

Conversion Units

Absolute Temperature (°R) = 460 + °F
Gas Volume at Standard Conditions = 359 cu.ft./lb.-mole
= 22.4 liters/gram-mole

Molecular Weight of Water = 18

CALCULATION OF DUST LOAD AT BOILER EXIT

Volume of Gas Sampled

(See Table 1 for values of R, Tm, M, P_{ft} and B)

$$C = R_{Corr.} \left[\frac{492}{460 + Tm}\right] \left[\frac{B-M-P_{ft}}{29.92}\right]$$

$$C = 77.52 \left[\frac{492}{460 + 98}\right] \left[\frac{26.71-7.86-.34}{29.92}\right] = 42.26 \text{ DSCF}$$

Volume of Wet Gas

$$Gs = R_{Corr.} \left[\frac{492}{460 + Tm}\right] \left[\frac{B-M}{29.92}\right] + W \left[\frac{22.4}{18 \times 28.32}\right]$$

$$= 77.52 \left[\frac{492}{460+98}\right] \left[\frac{26.71-7.86}{29.92}\right] + 450 \left[\frac{22.4}{18 \times 28.32}\right] = 62.81 \text{ WSCF}$$

Moisture Content of Gas

$$Hd = \frac{Gs - C}{C} = \frac{62.81-42.26}{42.26} = .486 \text{ cu ft } H_2O\text{/cu ft dry gas}$$

$$\% \ H_2O \text{ by volume} = \frac{Gs - C}{Gs} \times 100 = \frac{62.81-42.26}{62.81} \times 100 = 32.7\%$$

Gas Density

(See Table 2 for values of P_s and T_s)

Gas Weight = Dry Gas Weight + Water Content of Gas

$$= (30.687 \times 1.000) + (18 \times 0.0486) = 39.439$$

$$MW = \frac{39.439}{1.486} = 26.5 \text{ lb/mole}$$

$$MV = 359 \left[\frac{460+T_s}{492}\right] \left[\frac{29.92}{B-P_s}\right] = 359 \left[\frac{460 + 595}{492}\right] \left[\frac{29.92}{26.71-.40}\right]$$

$$= 875 \text{ cu ft /lb-mole}$$

$$\rho = \frac{MW}{MV} = \frac{26.5}{875} = 0.0303 \text{ lb/cu ft (at stack conditions)}$$

Volumetric Gas Flow

(See Table 2 for values of V_c, ρ_c, and A)

$$V = V_c \sqrt{\rho_c/\rho} = 34.66 \sqrt{.0730/.0303} = 53.80 \text{ ft /sec}$$

$$Q = V \times A = 53.80 \times 60 \text{ sec /min} \times 64.0 = 206{,}600 \text{ cu ft /min}$$

$$Q^1 = Q \times \frac{\text{Wt. of Dry Gas}}{\text{Wt. of Wet Gas}} \times \left[\frac{492}{460 + T_s}\right]\left[\frac{B-Ps}{29.92}\right]$$

$$= 206{,}600 \times \frac{1.000}{1.486} \times \left[\frac{492}{460 + 595}\right]\left[\frac{26.71-.40}{29.92}\right] = 54{,}900 \text{ DSCFM}$$

Dust Load

$$DL = \frac{N}{C} = \frac{17.76 \text{ grams}}{42.26} \times 15.43 \frac{\text{grains}}{\text{gram}} = 6.484 \text{ grains/DSCF}$$

$$\text{Total Loss} = DL \times Q^1 = \frac{54{,}900 \times 6.0484 \times 60 \text{ min /hr}}{7000 \text{ grains/lb}} = 3053 \text{ lb/hr}$$

PARTICULATE SAMPLING PROCEDURE AT THE STACK

Equipment

An R.A.C. Train Stack Sampler, manufactured by Research Appliance Company, was used for stack sampling in the testing program for No. 3 recovery system at Missoula. The unit conforms to specifications given in Volume 36, No. 247, of the Federal Register "Standards of Performance for New Stationary Samples - Method 5 Particulate Sampling." For ease of moving from port to port in the course of sampling, the sampling case was supported on a wheeled car in place of the factory supplied Duorail support. This sample train is illustrated in Figure 6.

Procedure

A new filter (Whatman GF/C) is oven dried, desicated and weighed. The sample train is assembled according to the manufacturer's instructions, with 100 ml of distilled water in each of the first two impingers; the third impinger is empty and approximately 200 grams of weighed dry silica gell is in the fourth.

The system is checked for leaks by plugging the nozzle tip. With the coarse-adjustment valve closed, the pump is turned on and the fine-adjustment valve regulated to maintain 10 inches of Mercury vacuum. At 10 inches of Mercury gage vacuum, the flow through the dry gas meter must not exceed 0.02 cu.ft. per minute, or the leaks must be found and corrected.

The stack is dividied into six equal areas with the sampling along two diameters located 90° apart for a total of 24 sample points. Factory supplied nomographs were used to establish isokinetic sampling at each point. Figure 5 illustrates this arrangement.

A velocity traverse is made with a calibrated "S" type pitot tube and inclined manometer. The indicated velocity is read off of the calibration chart and corrected for actual gas density. The average velocity multiplied by the stack area gives the total gas flow. (See Table 4).

The probe heater and filter oven are turned on for 15 minutes to warm up to 250°F. The impinger section of the sample case is filled with ice.

The probe is inserted into the stack with the nozzle located at the first position facing upstream. At the same time the vacuum pump is started and isokinetic flow established. The required sampling flow is obtained by nothing the pitot tube manometer reading (ΔP), setting this value on the operating nomograph, reading the corresponding ΔH and with first the coarse and then fine control valves, making adjustments until this ΔH is indicated on the orifice manometer. Each point is sampled for the same length of time with adjustments made as needed for isokinetic sampling. The pump is not turned off when moving from point to point, but only when changing ports. The time, gas meter reading ΔP, ΔH readings, temperature in and out of the gas meter, scrubber train outlet temperature and vacuum at the gas meter are recorded at the beginning,

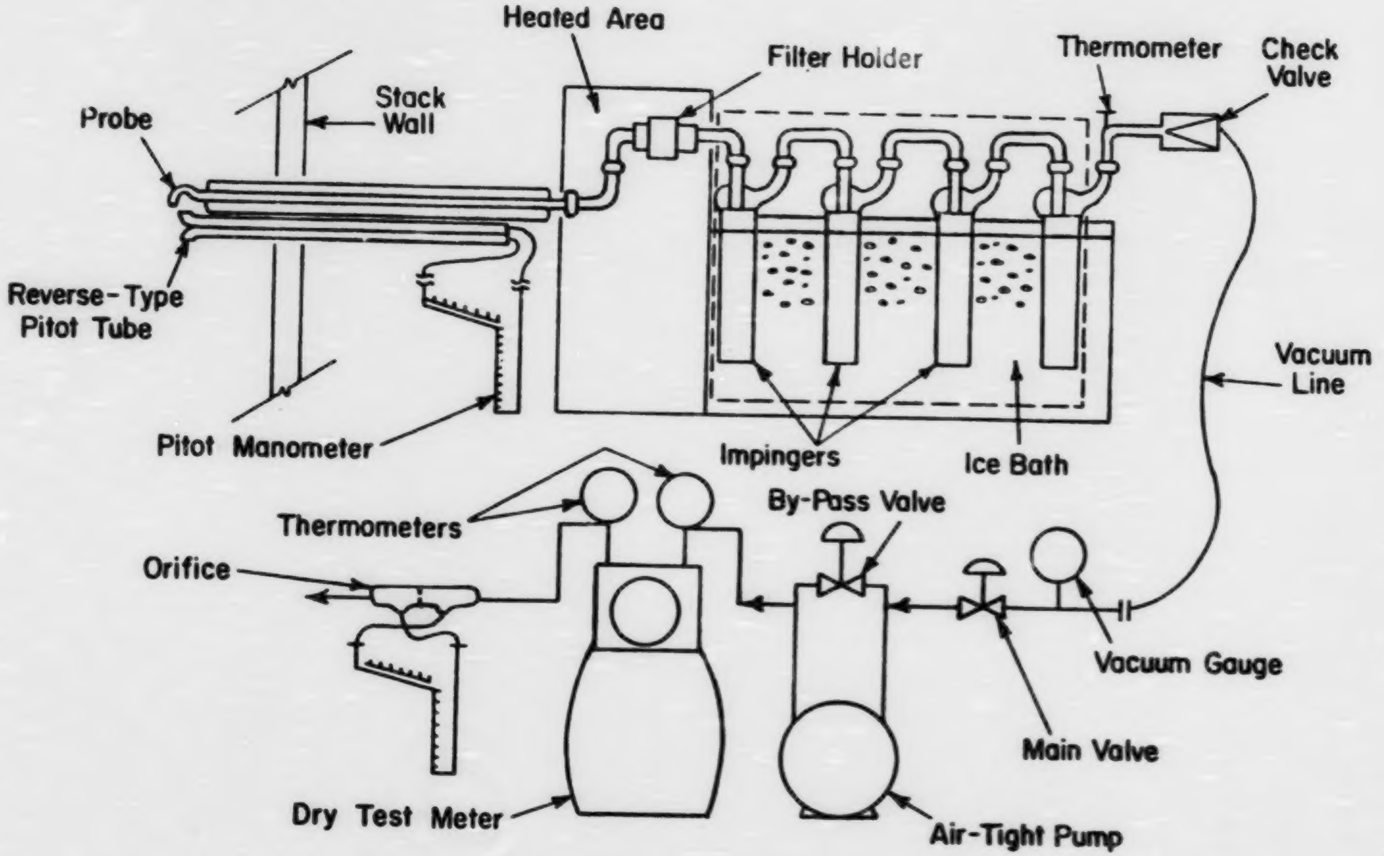

Heated Area
Filter Holder
Thermometer
Check Valve
Probe
Stack Wall
Reverse-Type Pitot Tube
Vacuum Line
Pitot Manometer
Impingers
Ice Bath
By-Pass Valve
Thermometers
Orifice
Vacuum Gauge
Main Valve
Dry Test Meter
Air-Tight Pump

Figure 6 EPA particulate sampling train used for stack sampling

Table 4

DETERMINATION OF AVERAGE GAS VELOCITY IN STACK (V_c)

DATE	October 24, 1973	DUCT DIMENSIONS	56.75 $ft.^2$ (A)
SAMPLE STATION	No. 3 Stack	STACK TEMPERATURE	335°F. (Ts)
PITOT TUBE	B	STACK PRESSURE	.68 Hg" (Ps)
CALIBRATION DENSITY	.0730 (ρ_c)	BAROMETER	26.71 Hg"(B)

*Traverse Position	Probe Traverse (Inches)	Pitot Tube ΔP (H_2O")	Gas Velocity (Ft./sec.)
1 W	2.0	1.02	59.9
2	6.8	1.42	70.3
3	12.0	1.42	70.3
4	18.1	1.22	65.3
5	25.5	.89	56.2
6	36.1	.68	49.2
7	65.9	.20	25.6
8	76.5	.15	22.6
9	84.0	.15	22.6
10	90.0	.12	20.1
11	95.2	.12	20.1
12	100.0	.11	19.8
1 N		.37	36.1
2		.43	38.6
3		.46	40.3
4		.41	37.8
5		.39	37.0
6		.40	37.2
7		.36	35.6
8		.39	37.0
9		.43	38.6
10		.48	41.0
11		.54	43.2
12		.50	41.8
		Average	40.26
			(V_c)

* See Figure 5

the end, and at each change of position during the test. (See Table 5).

When the test is complete, the train is dismantled and the sample removed to the lab for analysis. As much loose dust as possible is brushed from the inside of the nozzle, probe and cyclone and added to the filter catch. The filter is carefully removed, dried and weighed. The entire probe and train from the nozzle through the filter holder is washed with distilled water. The wash water is collected, evaporated in tared breakers and the net increase in weight added to the weight collected on the filter. The total liquid in the impinger train is measured. The wet silica gel is weighed and the increased weight of water is converted to volume (1 gram = 1 milliliter), and added to the total water. Subtracting the original 200 ml gives the volume of collected condensate.

The total gas volume measured at the gas meter is corrected to dry standard conditions of 70°F and 29.92 inches of Mercury. The total weight of dust collected, divided by the corrected gas volume, gives the grain loading. This is reported as grains of dust per dry standard cubic foot of gas.

The amount of collected condensate is used to calculate the stack gas moisture. The gas density is corrected for temperature, pressure, and moisture. The indicated stack velocity is corrected for gas density and the actual total gas flow calculated from the average velocity and stack area.

The total flow is corrected to dry standard conditions. By multiplying the flow by the dust loading, the total weight of dust lost is obtained.

Precipitator efficiency is then calculated by subtracting the total weight of dust lost up the stack from the total weight of dust at the boiler exit (precipitator inlet) to determine the weight of dust removed by the precipitator. Dividing the dust removed by the dust to the precipitator and multiplying by 100 gives the percent efficiency.

Sample calculations follow

Table 5

DETERMINATION OF METERED GAS VOLUME (R)

DATE	October 24, 1973	TEST NO.	1
SAMPLE STATION	No. 3 Stack	BAROMETER	26.71 Hg" (B)
TESTERS	Boschee and Horton	DUCT DIMENSIONS	56.75 Ft.^{2} (A)

Traverse *Position	Clock Time	Meter Vol. (Cu.ft.)	Pitot Tube $\Delta P(H_2O")$	Orifice $\Delta H(H_2O")$	Meter Temp(°F) In	Meter Temp(°F) Out	Impinger (°F)	Pump Vac. (Hg")
	**10:45	853.50	-	-	-	-	-	-
1 W	10:48	855.00	1.02	1.80	91	91	85	4.9
2	10:51	857.80	1.55	2.62	95	92	65	6.7
3	10:54	860.50	1.55	2.62	99	92	65	7.3
4	10:57	863.00	1.40	2.40	105	93	90	7.0
5	11:00	865.90	1.30	2.30	107	94	90	6.8
6	11:03	868.40	1.07	1.90	108	95	90	6.0
7	11:06	870.70	.70	1.28	109	96	90	4.5
8	11:09	872.00	.26	.48	109	98	90	2.5
9	11:12	873.20	.20	.38	108	98	75	2.1
10	11:15	874.30	.17	.32	107	98	75	2.1
11	11:18	875.30	.16	.31	107	99	75	2.1
12	11:21	876.40	.14	.28	107	100	75	2.0
	**11:26							
1 N	11:29	877.80	.22	.41	105	100	70	2.6
2	11:32	879.00	.32	.60	104	101	70	3.1
3	11:35	880.40	.38	.70	106	102	70	3.2
4	11:38	882.00	.30	.58	108	102	65	3.1
5	11:41	883.40	.28	.53	109	102	65	3.0
6	11:44	884.70	.25	.48	110	103	65	2.9
7	11:47	886.00	.25	.48	111	104	65	2.9
8	11:50	887.30	.28	.53	111	104	65	3.0
9	11:53	888.70	.32	.60	111	105	65	3.1
10	11:56	890.40	.45	.87	111	105	65	3.9
11	11:59	892.10	.48	.91	112	106	65	4.1
12	12:02	893.80	.40	.77	114	106	65	3.8
		Total - 40.30 (R)		Avg. - 1.01 (ΔH)		Avg. - 103 (Tm)		

* See Figure 5

** Starting Time

CALCULATION OF DUST LOAD AT STACK

Volume of Gas Sampled

(See Table 3 for Values of R, Tm, B and ΔH)

$$C = R \left[\frac{492}{460 + Tm}\right] \left[\frac{B + \Delta H/13.6}{29.92}\right]$$

$$C = 40.30 \left[\frac{492}{460 + 103}\right] \left[\frac{26.71 + 1.01/13.6}{29.92}\right] = 31.51 \text{ DSCF}$$

Volume of Wet Gas

$$Gs = R \left[\frac{492}{460 + Tm}\right] \left[\frac{B + \Delta H/13.6}{29.92}\right] + W \left[\frac{22.4}{18 \times 28.32}\right]$$

$$= 40.30 \left[\frac{492}{460 + 103}\right] \left[\frac{26.71 + 1.01/13.6}{29.92}\right] + 314.9 \left[\frac{22.4}{18 \times 28.32}\right]$$

$$= 45.36 \text{ WSCF}$$

Moisture Content of Gas

$$Hd = \frac{Gs - C}{C} = \frac{45.36 - 31.51}{31.51} = .440 \text{ cu ft } H_2O\text{/cu ft dry gas}$$

$$\% \ H_2O \text{ by volume} = \frac{Gs - C}{Gs} \times 100 = \frac{45.36 - 31.51}{45.36} \times 100 = 30.5\%$$

Gas Density

(See Table 4 for values of Ps and Ts)

Gas Weight = Dry Gas Weight + Water Content of Gas

= (30.687 x 1.000) + (18 x 0.440) = 38.607

$$MW = \frac{38.607}{1.440} = 26.8 \text{ lb /mole}$$

$$MV = 359 \left[\frac{460 + Ts}{492}\right] \left[\frac{29.92}{B-Ps}\right] = 359 \left[\frac{460 + 335}{492}\right] \left[\frac{29.92}{26.71 - .05}\right]$$

$$= 651 \text{ cu ft /lb mole}$$

$$\rho = \frac{MW}{MV} = \frac{26.8}{651} = 0.0412 \text{ lb /cu ft (at stack conditions)}$$

Volumetric Gas Flow

(See Table 4 for values of V_c, P_c and A)

$$V = Vc\sqrt{2/\rho} = 40.26\sqrt{.0750/.0412} = 54.32 \text{ ft /sec}$$

$$Q = V \times A = 54.32 \times 60 \frac{\text{sec.}}{\text{min}} \times 56.75 = 185{,}000 \text{ cu ft /min}$$

$$Q^1 = Q \times \frac{\text{Wt. of Dry Gas}}{\text{Wt. of Wet Gas}} \times \left[\frac{492}{460 + Ts}\right]\left[\frac{B - Ps}{29.92}\right]$$

$$= 185{,}000 \times \frac{1.000}{1.440} \times \left[\frac{492}{460 + 335}\right]\left[\frac{26.71 - .05}{29.92}\right] = 70{,}800 \text{ DSCFM}$$

Dust Load

$$DL = \frac{N}{C} = \frac{.0515 \text{ grams}}{31.51} \times 15.43 \frac{\text{grains}}{\text{grams}} = .0255 \text{ grains/DSCF}$$

$$\text{Total Loss} = DL \times Q^1 = \frac{70{,}800 \times .0255 \times 60 \text{ min/hr}}{7000 \text{ grains/lb}}$$

$$= 15.5 \text{ lb /hr}$$

Precipitator Collection Efficiency

$$E = \frac{\text{In-Out}}{\text{In}} = \frac{3053 - 15.5}{3053} \times 100 = 99.5\%$$

APPENDIX D

BLACK LIQUOR SOLIDS DETERMINATION

The liquor was collected in a tared graduated cylinder and the volume read immediately before the sample cooled. In the laboratory the outside of the cylinder is cleaned and dried. The cylinder and contents are weighed and the cylinder tare subtracted to obtain the net weight of liquor. The net weight in grams divided by the volume in milliliters and multiplied by 8.33 gives the liquor density at line conditions in pounds per gallon.

About 15 grams of well mixed liquor are transferred to a tared aluminum dish and quickly weighed. After drying for 24 hours in a forced circulation oven at 105°C, the samples are cooled in a desiccator and reweighed. The net dry weight is expressed as a percentage of the net wet weight and reported as oven-dry solids.

The values for both black liquor density and percent solids are needed for the calculation of boiler loading as shown in the example given on page 141.

APPENDIX E

Table 6

WEEKLY AVERAGES FOR SULFIDITY, TRS, AND SO_2 (1971-1973)

Week Ending	Sulfidity (%)	Average TRS (ppm)	Average SO_2 (ppm)
6-30-71	27.4	9.4	5
7-11-71	26.1	2.6	2
7-18-71	27.3	0.1	0
7-25-71	27.7	0.1	0
8-1-71	28.2	0.5	6
8-8-71	28.7	1.3	12
8-15-71	28.9	2.8	13
10-24-71	30.0	12.7	137
10-31-71	29.7	6.0	51
11-7-71	29.2	3.9	53
11-14-71	27.8	2.5	25
11-21-71	27.6	11.4	32
11-28-71	28.3	13.0	16
12-5-71	29.3	13.6	39
12-12-71	29.9	4.8	112
12-19-71	30.0	24.8	60
1-2-72	29.3	15.8	48
1-9-72	29.5	25.1	93
1-16-72	29.5	15.1	40
1-23-72	29.4	18.8	100
1-30-72	28.9	11.3	65
2-6-72	29.2	13.7	97
2-13-72	29.5	12.3	94

Week Ending	Sulfidity (%)	Average TRS (ppm)	Average SO_2 (ppm)
2-20-72	29.4	10	80
2-27-72	30.5	6.4	147
3-5-72	30.1	14.2	128
3-12-72	29.8	8.7	89
3-19-72	29.2	8.7	93
3-26-72	29.7	8.5	72
4-2-72	29.2	5.3	55
4-9-72	28.7	1.3	8
4-16-72	28.5	2.6	65
4-23-72	28.3	1.0	57
4-30-72	29.8	5.7	47
5-7-72	29.2	10.1	108
5-14-72	29.4	9.4	71
5-21-72	30.8	4.5	58
5-28-72	29.3	8.9	36
6-4-72	28.8	17.3	61
6-11-72	29.5	5.1	43
6-18-72	30.4	10.0	36
6-25-72	29.8	10.3	58
7-2-72	30.6	12.2	35
7-9-72	28.5	NA	NA
7-16-72	28.3	7.0	28
7-23-72	29.5	17.2	77
7-30-72	30.0	7.3	25
8-6-72	29.6	2.1	65

Week Ending	Sulfidity (%)	Average TRS (ppm)	Average SO_2 (ppm)
8-13-72	29.5	6.4	62
8-20-72	29.5	2.1	65
8-27-72	30.3	5.7	11
9-3-72	30.4	16.6	33
9-10-72	31.2	12.3	35
9-17-72	30.2	15.3	15
9-24-72	30.0	7.5	7
10-1-72	29.3	NA	NA
10-8-72	27.4	6.0	16
10-15-72	28.2	8.8	28
10-22-72	29.2	3.5	31
10-29-72	29.9	2.3	69
11-5-72	30.7	15.1	136
11-12-72	29.6	5.2	61
11-19-72	28.3	2.6	54
11-26-72	28.6	7.0	92
12-3-72	28.6	8.2	44
12-10-72	28.2	10.9	133
12-17-72	28.7	10.4	91
12-24-72	28.8	6.4	106
12-31-72	28.6	6.8	135
1-7-73	28.7	10.1	59
1-14-73	28.7	8.0	71
1-21-73	29.8	5.4	77
1-28-73	29.8	6.6	31

Week Ending	Sulfidity (%)	Average TRS (ppm)	Average SO_2 (ppm)
2-4-73	29.1	13.4	91
2-11-73	27.6	9.4	138
2-18-73	28.8	5.7	56
2-25-73	27.6	NA	NA
3-4-73	27.2	10.4	36
3-11-73	27.0	5.0	16
3-18-73	27.6	6.7	43
3-25-73	27.6	12.4	53
4-1-73	27.5	4.7	20
4-8-73	27.1	15.6	35
4-15-73	28.6	12.4	79
4-22-73	28.8	9.1	36
4-29-73	29.9	5.7	89
5-6-73	30.9	7.7	42
5-13-73	30.4	4.0	47
5-20-73	29.2	3.9	61
5-27-73	30.2	3.8	64
6-3-73	30.3	6.5	43
6-10-73	29.5	3.6	49
6-17-73	28.3	1.4	30
6-24-73	28.3	10.4	127
7-1-73	28.8	9.0	145
7-8-73	29.6	NA	NA
7-15-73	28.9	1.7	60
7-22-73	31.3	5.8	43
7-29-73	32.0	8.3	374

Week Ending	Sulfidity (%)	Average TRS (ppm)	Average SO_2 (ppm)
8-5-73	32.3	12.3	201
8-12-73	31.1	19.5	172
8-19-73	30.4	21.9	197
8-26-73	30.4	13.4	119
9-2-73	29.3	13.7	96
9-9-73	27.2	15.8	85
9-16-73	27.8	8.7	71
9-23-73	29.1	11.6	53
9-30-73	29.4	15.6	108
10-7-73	29.1	11.4	279
10-14-73	29.9	8.6	182
10-21-73	31.9	26.9	274
10-28-73	32.1	25.7	353
11-4-73	32.9	23.0	197
11-11-73	31.6	17.9	132
11-18-73	30.8	17.6	68
11-25-73	29.5	7.9	94
12-2-73	28.2	14.3	5
12-9-73	27.6	5.1	11
12-16-73	27.5	3.7	7
12-23-73	26.5	6.6	13
12-30-73	24.9	2.7	Negligible
1-6-74	24.4	1.9	Negligible

APPENDIX F

STATISTISTICAL DATA ANALYSIS
METHODS FOR COMPUTING CONFIDENCE LIMITS

1. In the experiment being analyzed sample data were obtained and straight line was fit to the data by the method of least squares. Assuming certain conditions[1] we are able to estimate the universe values of A and B (intercept and slope) from our sample values a and b.

   The 95% confidence limits for B are given by $b \pm t_{0.025}\, s_{y\cdot x} / \sigma_x \sqrt{N}$

   where $t_{0.025}$ is the 0.025 point of the "t" distribution for $n=N-2$. (In our cases with the large number of values, this is approximately 1.96). The standard error of estimate $s_{y\cdot x}$ is the square root of the mean square deviation about the regression line. Sigma is the standard deviation of x in the universe. (Our estimate for σ_x will be s_x for all data points under consideration).

   For example, in the case 3 - 7, Log SO_2 vs. Sulfidity, $b_{yx} = .1278$,

   $s_{y.x} = .4702$, $s_x = 2.0818$ and $N = 69$.
   $.1278 \pm 1.96\ (.027) = .1278 \pm .052 = .076,\ .180$

   We conclude that our chances are 0.95 that the universe regression coefficient will be included between the lower limit of 0.076 and upper limit of 0.180.

   Estimates of the standard errors of estimates for the sample intercepts and slopes are:

   $s_{a_{y.x}}^{2} = s_{y.x}^{2} / N$ and $s_{b_{yx}}^{2} = s_{y.x}^{2} / \sigma_x^{2} N$.
   The latter was used in the calculation of confidence limits.

2. The confidence limits for the least-squares estimate of the universe line of regression $Y_r = a_{y.x} + b_{yx} X$ can be determined as follows:

   $$Y_r = a_{y.x} + b_{yx} X \pm t_{0.025} \sqrt{s_{a_{y.x}}^{2} + s_{b_{yx}}^{2} X^2}$$

   These limits are a quadratic form of X and form parabolic loci around the sample line of regression. These loci are 0.95 confidence limits for the values of Y_r, but they are not strictly confidence limits for the universe line as a whole.

3. The equation for prediction limits for individual values about a regression line is as follows:

   $$Y = a_{y.x} + b_{yx} X \pm t_{0.025} \sqrt{s_{a_{y.x}}^{2} + s_{b_{yx}}^{2} X^2 + s_{y.x}^{2}}$$

   The last term under the radical is the mean square deviation about the regression line.

   These limits also form parabolic loci around the sample line of regression. It should be noted that predictions of the dependent variable "y" are subject to the least error when the independent variable "x" is near its mean--the narrowest area of the limits.

Table 7a

95% CONFIDENCE LIMITS FOR INDIVIDUAL VALUES ABOUT A REGRESSION LINE

Figure 12:

Boiler Exit Dust Load vs. Boiler Loading

$Y = 62.1\,X - 1940;\ \bar{Y} = 4156,\ \bar{X} = 98.1$

X Value	Lower Limit	Upper Limit
70	1110.6	3706.6
80	1747.3	4312.0
90	2377.3	4924.2
98.14	2885.2	5427.5
100	3000.6	5543.1
110	3617.0	6168.9
120	4226.6	6801.5

Figure 13:

Precipitator Outlet Dust Load vs. Boiler Loading

All data excluding low efficiencies:

$Y = 1.33\,X - 89;\ \bar{Y} = 39.4,\ \bar{X} = 96.8$

X Value	Lower Limit	Upper Limit
70	-19.06	26.63
80	-5.51	39.61
90	7.91	52.72
96.82	16.99	61.73
100	21.20	65.96
110	34.35	79.33
120	47.38	92.83

Figure 14:

TRS Emissions vs. Excess O_2

All Data: $Y = 29.7 - 8.3\,X;\ \bar{Y} = 10.4,\ \bar{X} = 2.3$

X Value	Lower Limit	Upper Limit
0	4.98	54.52
1	-2.39	45.27
2	-10.26	36.53
2.33	-12.98	33.76
3	-18.66	28.31
4	-27.58	20.61

Table 7b

95% CONFIDENCE LIMITS FOR INDIVIDUAL VALUES ABOUT A REGRESSION LINE (continued)

Figure 15:

Log SO_2 vs. Sulfidity

$Y = 0.128\,X - 2.0;\ \overline{Y} = 63,\ \overline{X} = 29.4$

X Value	Lower Limit	Upper Limit
26	.42	2.31
28	.68	2.55
29.44	.87	2.73
31	1.07	2.93
33	1.31	3.20

Figure 16:

Total Air Flow vs. Boiler Loading

All Data: $Y = 27.3 + 3.37\,X;\ \overline{Y} = 358,\ \overline{X} = 98.2$

X Value	Lower Limit	Upper Limit
70	200.44	325.77
80	234.88	358.70
90	268.99	391.95
98.22	296.78	419.52
100	302.77	425.52
110	336.23	459.42
120	369.36	493.95

Figure 18:

Precipitator Collection Efficiency vs. Precipitator Inlet Gas Volume
All data excluding low efficiencies

$Y = 100.78 - .009\,X;\ \overline{Y} = 99.1,\ \overline{X} = 187.5$

X Value	Lower Limit	Upper Limit
140	99.02	100.02
150	98.93	99.92
160	98.84	99.83
170	98.76	99.74
180	98.67	99.65
187.54	98.60	99.58
190	98.58	99.56
200	98.49	99.47
210	98.40	99.38

Table [illegible]

ANALYSIS OF REGRESSION LINES

Figure 19:

TRS Emissions vs. Excess O_2

95% Confidence Limits	Lower	Upper
Slope:	-4.78	-11.84
Intercept:	7.51	13.27

	Intercept	Slope	at $\bar{X}$ = 2.33, Y =
Low (26-28%) Sulfidity	16.01	-4.22*	6.18*
Normal (28-30%) Sulfidity	30.88	-9.82	8.00
High (31-33%) Sulfidity	56.73	-15.64*	20.29*

Figure 20:

SO_2 Emissions (Log Function) vs. Sulfidity

95% Confidence Limits	Lower	Upper
Slope:	.073	.182
Intercept:	1.688 (49)	1.915 (82)

	Intercept	Slope	at $\bar{X}$ = 29.44, Y =
Low (0-1.95%) Excess Oxygen	-2.73	.16	1.91 (81)
Normal(2.00-3.00%)Excess Oxygen	-1.92	.13	1.78 (60)
High (3.10-4.00%) Excess Oxygen	Not Significant		

Figure 21:

Total Air Flow vs. Boiler Loading

95% Confidence Limits	Lower	Upper
Slope:	2.92	3.82
Intercept:	352.67	363.57

	Intercept	Slope	at $\bar{X}$ = 98.22, Y =
Low (35%) Primary Air	19.15	3.59	372*
Normal (45%) Primary Air	33.69	3.28	356
High (55%) Primary Air	16.88	3.41	351*

* Exceeds confidence limits

APPENDIX G

COMPLETE EPA TEST DATA FOR BASIC PROGRAM

GLOSSARY FOR DATA SHEETS IN TABLES 9, 10, 11

Liquor flows - Measured with a magnetic flow meter and continuously recorded on a strip chart in gallons per minute.

Liquor densities - An average of two actual measurements during each test period.

Liquor solids - An average of two black liquor samples collected during each test period with solids being determined by oven drying a 12-18 gram sample of black liquor for 24 hours at 105°C.

Boiler loading - Actual true black liquor solids throughput divided by design solids throughput, corrected for the BTU value in use at that time.

EXAMPLE: No 3 recovery design - 1,400,000 lbs true black liquor solids per day at 6600 BTU/lb

Hoerner Waldorf black liquor contains 6,515 BTU's/lb

Therefore, corrected design solids throughput is:

$$1{,}400{,}000 \times \frac{6600}{6515} = 1{,}418{,}000 \text{ lbs/day}$$

Given:		
	Sluice flow	140 gal/min.
	% Solids	62.0%
	B.L.density	11.0 lb/gal

Boiler loading would then be:

$$\frac{140 \text{ gal/min} \times .62 \times 11 \text{ lb/gal} \times 1440 \text{ min/day}}{1{,}418{,}000 \text{ lb/day}} \times 100 = 97.0\%$$

Salt cake - Is added via a calibrated screw conveyor. Salt cake is the basic makeup chemical for the Kraft process and controls the sulfidity level.

Nozzle size - The diameter of the nozzle in 32nds of an inch. e.g., a size 40 nozzle is 3.175 cm (1.25 inches) in diameter.

Nozzle pressure - The liquor line pressure (psig).

Nozzle backsweep - The vertical upper and lower limits of nozzle movement expressed in degrees with 0 degrees at the horizontal position

Nozzle sidesweep - The rotation of the nozzle expressed in degrees with 0 degrees at the vertical position.

Air flows - The amount of air entering the furnace at the primary, secondary, or tertiary air ports. It is measured by pressure differential in the duct and recorded continuously on a strip chart.

Total air - The summation of the individual primary, secondary, and tertiary air flows.

Combustion air temperature - The temperature of the combustion air after it has been heated by a steam heat exchanger and before it enters the recovery boiler. It is measured and recorded continuously on a strip chart.

Excess O_2 - The percentage of oxygen leaving the furnace. Measurement based upon a paramagnetic principle. It is calibrated bimonthly, using 1.0 and 9.0% oxygen standards and recorded continuously on a strip chart.

TRS and SO_2 Averages - The amount of TRS and SO_2 as ppm (dry gas basis) leaving the recovery boiler stack during the test period as measured with a Barton titrator. Accuracies and calibration frequencies are discussed in the section of this report entitled testing procedures.

Sulfidity - The percentage ratio of sodium sulfide to total alkali (NaOH, Na_2S, and Na_2CO_3), all expressed as Na_2O. The daily sulfidity is an average of six white and three green liquor titrations run by lab personnel.

Steam flow - The amount of 600 psig, 750° F steam produced in lbs/hr from the recovery boiler. The Hoerner Waldorf No. 3 recovery boiler will produce 235,000 lbs/hr of steam at design solids loading.

Boiler exit and precipitator outlet conditions - ACFM, DSCFM, temperatures, particulate loadings, and precipitator efficiencies are either directly measured or calculated from data collected during each test period. An example of actual data collected and sample calculations will be found in the APPENDIX of this report.

Precipitator inlet conditions - ACFM - The gas volume entering the precipitator at actual pressure and temperature conditions.

Volume at 400° F - The precipitator was designed to collect 99.125% of the incoming particulate at this temperature with an air volume of 207,500 ACFM.

TABLE OF CONVERSION FACTORS
(English to Metric Units)

Multiply	by	to obtain
cubic feet	0.02832	cubic meters
degrees Fahrenheit(°F)	(-32) x 5/9	degrees centigrade(°C)
gallons	3.785	liters
pounds	0.454	kilograms
pounds per gallon	0.1195	kilograms per liter
pressure (PSI)	760/14.7	pressure(mm.of mercury)

Table 9

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	0.5-1.5
TEST DATE	3-5-73	3-5-73	3-6-73	3-6-73	3-7-73
SLUICE TANK LIQUOR					
Flow (gpm)	165	165	168	168	161
Density (lbs/gal)	11.1	11.1	11.2	11.1	11.5
Solids (%)	60.0	59.7	59.7	60.0	60.3
BOILER LOADING (%)	108	108	111	110	110
SALT CAKE (lbs/min)	40	40	40	45	45
SULFIDITY - (DAILY AVG.%)	27.7	27.7	26.7	26.7	27.0
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	39	39	39	39	39
Liquor Temp. (°F)	243	245	245	245	245
Backsweep (°)	-6 to -19	-6 to -19	-6 to -19	-6 to -19	-6 to -19
Sidesweep (°)	12Lto 21R	12Lto 21R	12Lto 21R	12Lto 21R	12Lto 21R
COMBUSTION AIR TEMP (°F)	243	242	240	240	245
AIR FLOW					
Primary (M lbs/hr)	175	175	177	177	165
(% of Total)	44	45	45	45	45
Secondary (M lbs/hr)	165	160	158	158	150
(% of Total)	42	41	40	40	41
Tertiary (M lbs/hr)	55	56	57	57	52
(% of Total)	14	14	15	15	14
Total (M lbs/hr)	395	391	392	392	367
EXCESS O_2 (%)	2.0	2.0	2.0	2.0	0.7
TRS AVG. (ppm)	0.1	0.1	1.0	1.0	25.5
SO_2 AVG (ppm)	9.0	9.0	13	13	18.5
STEAM FLOW (M lbs/hr)	250	245	245	255	250
BOILER EXIT CONDITIONS					
Temp (°F)	656	615	683	662	645
ACFM (1000 cu.ft./min)	279	277	282	291	264
DSCFM(1000 cu.ft./min)	78.1	80.6	77.8	81.2	68.5
Grain Loading(gr/DSCF)	7.12	6.52	6.45	7.77	8.28
Particulate Load(lbs/hr)	4763	4502	4303	5408	5236
PRECIPITATOR INLET COND.					
Temp (°F)	410	415	420	430	415
ACFM(1000 cu.ft./min)	217	225	217	231	209
Volume @ 400°F	214	221	212	223	205
PRECIPITATOR OUTLET COND.					
Temp (°F)	368	390	400	418	Data
ACFM (1000 cu.ft./min)	232	217	240	224	Missing
DSCF (1000 cu.ft./min)	88.4	82.8	91.8	83.8	"
Grain Loading(gr/DSCF)	.0828	.0751	.0689	.0751	"
Particulate Loading(lbs/hr)	69.2	53.3	54.2	53.9	"
PRECIPITATOR EFFICIENCY(%)	98.5	98.8	98.7	99.0	-

COMPLETE EPA TEST DATA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	35/50/15	35/50/15	35/50/15	35/50/15
Excess O_2 (%)	0.5-1.5	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	3-7-73	3-8-73	3-8-73	3-9-73	3-9-73
SLUICE TANK LIQUOR					
Flow (gpm)	161	161	162	162	162
Density (lbs/gal)	11.2	11.2	11.2	11.2	11.2
Solids (%)	60.4	60.5	60.5	59.4	59.6
BOILER LOADING (%)	108	108	108	106	107
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	27.0	27.0	27.0	27.8	27.8
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	39	39	39	38	38
Liquor Temp. (°F)	245	245	245	245	245
Backsweep (°)	-6 to -19	-6 to -19	-6 to -19	-6 to -19	-6 to -19
Sidesweep (°)	12L to 21R	12L to 21R	12L to 21R	12L to 21R	12L to 21R
COMBUSTION AIR TEMP (°F)	240	235	240	240	240
AIR FLOW					
Primary (M lbs/hr)	167	158	157	158	158
(% of Total)	44	38	38	38	38
Secondary (M lbs/hr)	155	200	200	200	200
(% of Total)	41	48	48	48	48
Tertiary (M lbs/hr)	55	58	59	57	57
(% of Total)	15	14	14	14	14
Total (M lbs/hr)	377	416	416	415	415
EXCESS O_2 (%)	0.7	1.5	1.5	1.7	1.7
TRS AVG. (ppm)	25.5	3.5	3.5	4.0	4.0
SO_2 AVG (ppm)	18.5	17.5	17.5	15.5	15.5
STEAM FLOW (M lbs/hr)	255	260	260	260	255
BOILER EXIT CONDITIONS					
Temp (°F)	654	681	666	646	689
ACFM (1000 cu.ft./min)	274	293	282	283	300
DSCFM(1000 cu.ft./min)	76.6	81.9	79.1	80.5	81.9
Grain Loading(gr/DSCF)	8.18	8.57	7.93	9.13	8.10
Particulate Load(lbs/hr)	5370	6012	5373	6295	5674
PRECIPITATOR INLET COND.					
Temp (°F)	410	425	420	420	425
ACFM(1000 cu.ft./min)	214	227	220	225	231
Volume @ 400°F	212	220	215	220	224
PRECIPITATOR OUTLET COND.					
Temp (°F)	400	405	407	408	413
ACFM (1000 cu.ft./min)	234	248	260	260	266
DSCF (1000 cu.ft./min)	88.0	94.1	98.3	96.6	97.8
Grain Loading(gr/DSCF)	.0985	.0602	.0639	.0794	.0686
Particulate Loading(lbs/hr)	74.3	48.5	53.7	65.7	57.5
PRECIPITATOR EFFICIENCY(%)	98.6	99.2	99.0	99.0	99.0

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	
Boiler Loading (% of Design)	110	110	110	110	
Air Distribution (1°/2°/3°-%)	55/30/15	55/30/15	55/30/15	55/30/15	
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	
TEST DATE	3-12-73	3-12-73	3-13-73	3-13-73	
SLUICE TANK LIQUOR					
Flow (gpm)	176	177	177	179	
Density (lbs/gal)	11.2	11.1	11.2	11.1	
Solids (%)	60.8	60.9	59.5	59.0	
BOILER LOADING (%)	118	117	116	116	
SALT CAKE (lbs/min)	45	45	45	45	
SULFIDITY - (DAILY AVG.%)	27.7	27.7	27.7	27.7	
NOZZLE CONDITIONS					
Size	40	40	40	40	
Pressure (PSI)	38	38	38	38	
Liquor Temp. (°F)	245	245	245	245	
Backsweep (°)	-6 to -19	-6 to -19	-6 to -19	-6 to -19	
Sidesweep (°)	12L to 22R	12L to 22R	12L to 22R	12L to 22R	
COMBUSTION AIR TEMP (°F)	230	235	235	235	
AIR FLOW					
Primary (M lbs/hr)	210	210	210	210	
(% of Total)	54	53	53	53	
Secondary (M lbs/hr)	118	125	130	130	
(% of Total)	31	32	32	32	
Tertiary (M lbs/hr)	58	60	60	61	
(% of Total)	15	15	15	15	
Total (M lbs/hr)	386	395	400	401	
EXCESS O_2 (%)	2.4	2.4	2.7	2.7	
TRS AVG. (ppm)	2.5	2.5	2.6	2.6	
SO_2 AVG (ppm)	78	78	51	51	
STEAM FLOW (M lbs/hr)	260	255	250	245	
BOILER EXIT CONDITIONS					
Temp (°F)	696	714	700	680	
ACFM (1000 cu.ft./min)	292	311	308	312	
DSCFM(1000 cu.ft./min)	79.9	83.9	83.4	85.3	
Grain Loading(gr/DSCF)	8.59	8.89	5.63	7.44	
Particulate Load(lbs/hr)	5887	6400	4019	5441	
PRECIPITATOR INLET COND.					
Temp (°F)	425	435	425	445	
ACFM(1000 cu.ft./min)	232	237	235	248	
Volume @ 400°F	229	228	228	235	
PRECIPITATOR OUTLET COND.					
Temp (°F)	409	405	405	423	
ACFM (1000 cu.ft./min)	279	276	285	278	
DSCF (1000 cu.ft./min)	107	106	108	106	
Grain Loading(gr/DSCF)	.0862	.0939	.1051	.0924	
Particulate Loading(lbs/hr)	79.2	85.5	97.9	84.1	
PRECIPITATOR EFFICIENCY(%)	98.7	98.7	97.6	98.5	

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	0.5-1.5
TEST DATE	3-15-73	3-15-73	3-26-73	3-26-73	3-16-73
SLUICE TANK LIQUOR					
Flow (gpm)	152	152	156	155	152
Density (lbs/gal)	11.1	11.1	10.8	10.5	11.2
Solids (%)	60.0	59.9	60.2	59.2	60.3
BOILER LOADING (%)	99	99	102	100	101
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	27.3	27.3	27.5	27.5	26.1
NOZZLE CONDITIONS					
Size	38	38	38	38	38
Pressure (PSI)	39	38	38	39	38
Liquor Temp. (°F)	245	245	245	245	245
Backsweep (°)	-7 to -20	-7 to -20	-7 to -20	-7 to -20	-7 to -20
Sidesweep (°)	12L to 21R	12L to 21R	12L to 19R	12L to 19R	12L to 21R
COMBUSTION AIR TEMP (°F)	245	245	245	242	245
AIR FLOW					
Primary (M lbs/hr)	154	155	163	164	142
(% of Total)	45	45	45	45	44
Secondary (M lbs/hr)	135	137	142	142	133
(% of Total)	39	40	39	39	41
Tertiary (M lbs/hr)	54	53	60	60	50
(% of Total)	16	15	16	16	15
Total (M lbs/hr)	343	345	365	366	325
EXCESS O_2 (%)	2.0	2.0	2.4	2.4	1.0
TRS AVG. (ppm)	4.9	4.9	4.6	4.6	15.9
SO_2 AVG (ppm)	33.6	33.6	13.4	13.4	13.4
STEAM FLOW (M lbs/hr)	230	235	235	230	235
BOILER EXIT CONDITIONS					
Temp (°F)	588	574	615	629	605
ACFM (1000 cu.ft./min)	233	241	258	247	226
DSCFM(1000 cu.ft./min)	70.7	73.4	75.7	71.2	65.4
Grain Loading(gr/DSCF)	6.64	6.83	6.25	4.51	7.77
Particulate Load(lbs/hr)	4024	4297	4063	2756	4350
PRECIPITATOR INLET COND.					
Temp (°F)	390	390	410	400	385
ACFM(1000 cu.ft./min)	189	198	209	195	179
Volume @ 400°F	191	200	207	195	183
PRECIPITATOR OUTLET COND.					
Temp (°F)	371	373	388	387	376
ACFM (1000 cu.ft./min)	196	201	243	249	216
DSCF (1000 cu.ft./min)	77.5	78.4	93.5	95.8	83.3
Grain Loading(gr/DSCF)	.0464	.0388	.0403	.0366	.0443
Particulate Loading(lbs/hr)	30.8	26.1	31.6	33.8	31.6
PRECIPITATOR EFFICIENCY(%)	99.2	99.4	99.2	98.9	99.3

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	35/50/15	35/50/15
Excess O_2 (%)	0.5-1.5	3.5-4.5	3.5-4.5	2.0-3.0	2.0-3.0
TEST DATE	3-16-73	3-19-73	3-19-73	3-20-73	3-20-73
SLUICE TANK LIQUOR					
Flow (gpm)	151	151	151	151	156
Density (lbs/gal)	11.1	11.2	11.1	11.1	10.9
Solids (%)	60.6	60.7	60.7	59.8	59.3
BOILER LOADING (%)	101	101	100	99	100
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	26.1	27.6	27.6	28.2	28.2
NOZZLE CONDITIONS					
Size	38	38	38	38	38
Pressure (PSI)	38	38	38	38	40
Liquor Temp. (°F)	245	245	245	245	242
Backsweep (°)	-7 to -20	-5 to -21	-5 to -21	-6 to -21	-6 to -21
Sidesweep (°)	12L to 21R	12L to 19R	12L to 19R	12L to 19R	12L to 19R
COMBUSTION AIR TEMP (°F)	250	245	245	245	245
AIR FLOW					
Primary (M lbs/hr)	145	167	167	135	135
(% of Total)	44	44	44	35	36
Secondary (M lbs/hr)	132	162	162	188	188
(% of Total)	41	42	42	50	50
Tertiary (M lbs/hr)	50	55	55	50	50
(% of Total)	15	14	14	14	14
Total (M lbs/hr)	327	384	384	373	373
EXCESS O_2 (%)	1.0	3.6	3.6	2.2	2.2
TRS AVG. (ppm)	15.9	0.9	0.9	7.3	7.3
SO_2 AVG (ppm)	13.4	46.2	46.2	43.6	43.6
STEAM FLOW (M lbs/hr)	232	230	230	225	225
BOILER EXIT CONDITIONS					
Temp (°F)	597	604	627	635	608
ACFM (1000 cu.ft./min)	224	264	254	246	254
DSCFM(1000 cu.ft./min)	65.9	80.7	75.8	71.0	74.4
Grain Loading(gr/DSCF)	6.53	6.77	5.57	4.93	5.05
Particulate Load(lbs/hr)	3691	4679	3619	3001	3221
PRECIPITATOR INLET COND.					
Temp (°F)	390	410	400	400	410
ACFM(1000 cu.ft./min)	180	216	200	193	207
Volume @ 400°F	182	213	200	193	205
PRECIPITATOR OUTLET COND.					
Temp (°F)	373	396	390	380	393
ACFM (1000 cu.ft./min)	222	251	250	237	233
DSCF (1000 cu.ft./min)	85.8	98.0	97.8	91.7	88.7
Grain Loading(gr/DSCF)	.0450	.0444	.0476	.0364	.0382
Particulate Loading(lbs/hr)	33.8	37.3	39.9	28.6	29.1
PRECIPITATOR EFFICIENCY(%)	99.1	99.2	98.9	99.1	99.1

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	55/30/15	55/30/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	3-21-73	3-21-73	3-22-73	3-22-73	3-23-73
SLUICE TANK LIQUOR					
Flow (gpm)	154	154	152	152	157
Density (lbs/gal)	10.7	10.9	10.9	10.9	10.9
Solids (%)	59.1	59.2	60.1	60.3	59.9
BOILER LOADING (%)	96	97	101	101	103
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	26.9	26.9	28.1	28.1	27.2
NOZZLE CONDITIONS					
Size	38	38	38	38	38
Pressure (PSI)	38	40	38	38	39
Liquor Temp. (°F)	242	242	245	245	245
Backsweep (°)	-6 to -22	-6 to -22	-7 to -20	-7 to -20	-7 to -20
Sidesweep (°)	12L to 19R	12L to 19R	12L to 19R	12L to 19R	12L to 19R
COMBUSTION AIR TEMP (°F)	245	245	235	240	243
AIR FLOW					
Primary (M lbs/hr)	135	135	193	193	183
(% of Total)	36	36	52	52	54
Secondary (M lbs/hr)	185	188	122	122	108
(% of Total)	50	50	33	33	32
Tertiary (M lbs/hr)	50	50	55	56	49
(% of Total)	14	14	15	15	14
Total (M lbs/hr)	370	373	370	371	340
EXCESS O_2 (%)	2.4	2.4	3.5	3.5	2.5
TRS AVG. (ppm)	7.5	7.5	9.5	9.5	13.9
SO2 AVG (ppm)	55.2	55.2	62.9	62.9	77.4
STEAM FLOW (M lbs/hr)	223	225	225	235	230
BOILER EXIT CONDITIONS					
Temp (°F)	607	601	636	653	642
ACFM (1000 cu.ft./min)	249	254	272	265	244
DSCFM(1000 cu.ft./min)	72.5	79.6	79.9	75.9	71.5
Grain Loading(gr/DSCF)	6.24	5.47	5.22	6.53	5.77
Particulate Load(lbs/hr)	3881	3500	3578	4248	3531
PRECIPITATOR INLET COND.					
Temp (°F)	410	410	420	410	400
ACFM(1000 cu.ft./min)	203	209	218	201	191
Volume @ 400°F	201	206	213	205	191
PRECIPITATOR OUTLET COND.					
Temp (°F)	408	396	393	405	395
ACFM (1000 cu.ft./min)	244	243	252	259	250
DSCF (1000 cu.ft./min)	89.8	91.1	97.0	92.2	96.5
Grain Loading(gr/DSCF)	.0357	.0408	.0479	.0501	.0425
Particulate Loading(lbs/hr)	27.6	31.9	39.8	42.6	35.1
PRECIPITATOR EFFICIENCY(%)	99.3	99.1	99.0	99.0	99.0

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	100	75	75	75	75
Air Distribution (1°/2°/3°-%)	55/30/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	3.5-4.5
TEST DATE	3-23-73	3-28-73	3-28-73	3-29-73	3-27-73
SLUICE TANK LIQUOR					
Flow (gpm)	157	115	115	121	114
Density (lbs/gal)	10.8	11.0	11.0	11.0	11.0
Solids (%)	60.0	58.7	59.0	58.8	59.4
BOILER LOADING (%)	103	73	74	77	74
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	27.2	27.8	27.8	26.9	27.1
NOZZLE CONDITIONS					
Size	38	32	32	32	32
Pressure (PSI)	39	40	40	40	40
Liquor Temp. (°F)	245	247	247	247	247
Backsweep (°)	-7 to -20	-6 to -20	-6 to -20	-6 to -20	-6 to -20
Sidesweep (°)	12L to 19R	12L to 19R	12L to 19R	12L to 19R	12L to 19R
COMBUSTION AIR TEMP (°F)	245	258	260	258	256
AIR FLOW					
Primary (M lbs/hr)	183	118	118	121	125
(% of Total)	54	45	45	46	46
Secondary (M lbs/hr)	108	106	106	105	111
(% of Total)	32	41	41	40	41
Tertiary (M lbs/hr)	49	36	36	36	36
(% of Total)	14	14	14	14	13
Total (M lbs/hr)	340	260	260	262	272
EXCESS O_2 (%)	2.5	2.5	2.5	2.2	3.2
TRS AVG. (ppm)	13.9	1.9	1.9	4.0	2.7
SO2 AVG (ppm)	77.4	21.2	21.2	16.1	20.3
STEAM FLOW (M lbs/hr)	232	170	175	180	170
BOILER EXIT CONDITIONS					
Temp (°F)	628	555	556	558	547
ACFM (1000 cu.ft./min)	247	178	176	179	180
DSCFM(1000 cu.ft./min)	72.8	53.8	51.7	54.0	55.2
Grain Loading(gr/DSCF)	6.31	5.96	6.92	6.95	6.72
Particulate Load(lbs/hr)	3942	2745	3068	3212	3190
PRECIPITATOR INLET COND.					
Temp (°F)	410	370	365	370	360
ACFM(1000 cu.ft./min)	197	145	143	146	143
Volume @ 400°F	195	150	149	151	148
PRECIPITATOR OUTLET COND.					
Temp (°F)	391	352	350	347	372
ACFM (1000 cu.ft./min)	253	174	170	177	177
DSCF (1000 cu.ft./min)	97.8	68.0	66.6	69.0	56.9
Grain Loading(gr/DSCF)	.0366	.0160	.0164	.0150	.0217
Particulate Loading(lbs/hr)	30.6	9.3	9.4	8.9	12.5
PRECIPITATOR EFFICIENCY(%)	99.2	99.7	99.7	99.7	99.6

COMPLETE EPA TEST DATA FOR 26-28% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	26-28	26-28	26-28	26-28	26-28
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	45/40/15	35/50/15	35/50/15	55/30/15	55/30/15
Excess O_2 (%)	3.5-4.5	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	3-27-73	4-2-73	4-3-73	3-30-73	4-4-73
SLUICE TANK LIQUOR					
Flow (gpm)	114	113	115	112	116
Density (lbs/gal)	11.0	11.2	11.3	11.2	11.1
Solids (%)	59.8	61.0	60.7	60.3	59.8
BOILER LOADING (%)	74	76	78	75	76
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	27.1	27.3	27.7	26.9	25.4
NOZZLE CONDITIONS					
Size	32	32	32	32	32
Pressure (PSI)	40	40	39	40	41
Liquor Temp. (°F)	247	247	245	250	248
Backsweep (°)	-6 to -20	-6 to -20	-10 to -17	-6 to -19	-5 to -19
Sidesweep (°)	12L to 17R	10L to 19R	10L to 19R	12L to 20R	10L to 18R
COMBUSTION AIR TEMP (°F)	256	252	256	252	255
AIR FLOW					
Primary (M lbs/hr)	125	105	102	134	138
(% of Total)	46	37	37	53	53
Secondary (M lbs/hr)	111	142	138	80	82
(% of Total)	41	49	49	32	32
Tertiary (M lbs/hr)	36	41	40	38	38
(% of Total)	13	14	14	15	15
Total (M lbs/hr)	272	288	280	252	258
EXCESS O_2 (%)	3.2	2.7	2.0	2.2	2.2
TRS AVG. (ppm)	2.7	7.8	6.6	1.3	16
SO_2 AVG (ppm)	20.3	42.0	51.7	3.8	120
STEAM FLOW (M lbs/hr)	175	180	185	185	180
BOILER EXIT CONDITIONS					
Temp (°F)	551	536	545	545	532
ACFM (1000 cu.ft./min)	178	173	175	183	174
DSCFM(1000 cu.ft./min)	54.3	56.6	57.0	57.0	55.2
Grain Loading(gr/DSCF)	6.69	5.90	6.20	7.43	6.93
Particulate Load(lbs/hr)	3113	2857	3548	3627	3277
PRECIPITATOR INLET COND.					
Temp (°F)	365	365	365	375	365
ACFM(1000 cu.ft./min)	145	145	145	151	145
Volume @ 400°F	151	150	150	156	150
PRECIPITATOR OUTLET COND.					
Temp (°F)	355	345	335	345	350
ACFM (1000 cu.ft./min)	172	177	171	177	182
DSCF (1000 cu.ft./min)	66.2	76.9	68.8	72.2	71.4
Grain Loading(gr/DSCF)	.0168	.0150	.0132	.0058	.0139
Particulate Loading(lbs/hr)	9.6	8.6	7.2	3.3	7.9
PRECIPITATOR EFFICIENCY(%)	99.7	99.7	99.8	99.9	99.7

Table 10

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	4-11-73	4-11-73	4-12-73	4-12-73	4-16-73
SLUICE TANK LIQUOR					
Flow (gpm)	165	160	157	157	166
Density (lbs/gal)	11.1	11.1	11.3	11.2	11.2
Solids (%)	62.5	62.6	61.2	60.9	61.9
BOILER LOADING (%)	114	109	106	106	114
SALT CAKE (lbs/min)	50	50	45	45	50
SULFIDITY - (DAILY AVG.%)	28.4	28.4	28.6	28.6	29.1
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	39	39	38	38	39
Liquor Temp. (°F)	245	245	245	245	245
Backsweep (°)	-5 to -22	-5 to -22	-5 to -2	-5 to -21	-8 to -16
Sidesweep (°)	5L to 15R	5L to 15R	5L to 15R	5L to 15R	5L to 15R
COMBUSTION AIR TEMP (°F)	230	235	230	235	230
AIR FLOW					
Primary (M lbs/hr)	190	178	178	178	190
(% of Total)	45	44	44	44	45
Secondary (M lbs/hr)	173	168	173	170	168
(% of Total)	41	42	42	42	40
Tertiary (M lbs/hr)	61	57	57	57	60
(% of Total)	14	14	14	14	15
Total (M lbs/hr)	424	403	408	405	418
EXCESS O_2 (%)	2.5	2.5	2.5	2.5	2.4
TRS AVG. (ppm)	6.7	6.7	10.1	10.1	0.9
SO_2 AVG (ppm)	39.2	39.2	148	148	39.5
STEAM FLOW (M lbs/hr)	260	255	240	240	255
BOILER EXIT CONDITIONS					
Temp (°F)	696	666	682	670	695
ACFM (1000 cu.ft./min)	294	246	263	280	289
DSCFM(1000 cu.ft./min)	81.4	78.6	80.4	79.4	80.5
Grain Loading(gr/DSCF)	7.78	8.41	5.36	7.66	6.73
Particulate Load(lbs/hr)	5428	5671	3692	5217	4294
PRECIPITATOR INLET COND.					
Temp (°F)	460	430	440	440	450
ACFM(1000 cu.ft./min)	234	218	223	225	228
Volume @ 400°F	219	211	213	215	215
PRECIPITATOR OUTLET COND.					
Temp (°F)	427	417	428	423	420
ACFM (1000 cu.ft./min)	291	246	280	280	283
DSCF (1000 cu.ft./min)	116.1	101.4	108.5	110.9	104.6
Grain Loading(gr/DSCF)	.1199	.0807	.1055	.1028	.1131
Particulate Loading(lbs/hr)	119.3	70.1	98.1	97.4	101.3
PRECIPITATOR EFFICIENCY(%)	97.8	98.8	97.3	98.1	97.6

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	35/50/15
Excess O_2 (%)	0.5-1.5	0.5-1.5	3.5-4.5	3.5-4.5	2.0-3.0
TEST DATE	4-13-73	4-13-73	4-17-73	4-17-73	4-18-73
SLUICE TANK LIQUOR					
Flow (gpm)	164	164	163	162	171
Density (lbs/gal)	11.2	11.2	11.1	11.1	11.3
Solids (%)	60.5	61.0	62.3	62.1	61.1
BOILER LOADING (%)	110	110	111	110	116
SALT CAKE (lbs/min)	50	50	50	50	50
SULFIDITY - (DAILY AVG.%)	28.2	28.2	27.6	27.6	28.4
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	39	39	39	39	38
Liquor Temp. (°F)	245	245	248	248	240
Backsweep (°)	-5 to -21	-5 to -21	-8 to -16	-5 to -20	-5 to -20
Sidesweep (°)	15L - 15R	15L to 15R	5L to 15R	6L to 23R	10L to 18R
COMBUSTION AIR TEMP (°F)	242	235	230	230	235
AIR FLOW					
Primary (M lbs/hr)	170	170	195	194	161
(% of Total)	43	44	45	45	39
Secondary (M lbs/hr)	161	161	172	173	197
(% of Total)	41	41	40	41	47
Tertiary (M lbs/hr)	61	57	62	61	58
(% of Total)	16	15	15	14	14
Total (M lbs/hr)	392	388	429	428	416
EXCESS O_2 (%)	1.0	1.0	3.3	3.3	2.0
TRS AVG. (ppm)	26.5	26.5	1.8	1.8	8.4
SO_2 AVG (ppm)	196	196	16.5	16.5	27.6
STEAM FLOW (M lbs/hr)	260	255	255	250	250
BOILER EXIT CONDITIONS					
Temp (°F)	680	678	636	665	676
ACFM (1000 cu.ft./min)	277	277	289	287	280
DSCFM (1000 cu.ft./min)	76.9	76.1	85.8	82.8	75.5
Grain Loading (gr/DSCF)	6.73	7.83	6.94	6.18	9.03
Particulate Load (lbs/hr)	4440	5107	5100	4384	5848
PRECIPITATOR INLET COND.					
Temp (°F)	440	430	440	440	435
ACFM (1000 cu.ft./min)	216	217	237	231	220
Volume @ 400°F	207	209	227	221	211
PRECIPITATOR OUTLET COND.					
Temp (°F)	410	407	417	422	408
ACFM (1000 cu.ft./min)	245	270	281	280	280
DSCF (1000 cu.ft./min)	91.8	101.9	108.6	106.8	104.7
Grain Loading (gr/DSCF)	.0653	.0733	.0866	.1160	.0549
Particulate Loading (lbs/hr)	51.4	64.0	80.6	106.2	49.2
PRECIPITATOR EFFICIENCY (%)	98.8	98.8	98.4	97.6	99.2

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	110	110	100	100	100
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	55/30/15	55/30/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	4-18-73	4-23-73	4-24-73	4-24-73	4-26-73
SLUICE TANK LIQUOR					
Flow (gpm)	168	157	149	147	155
Density (lbs/gal)	11.3	11.1	11.2	11.1	11.2
Solids (%)	61.4	62.3	62.3	64.3	60.8
BOILER LOADING (%)	115	107	103	103	104
SALT CAKE (lbs/min)	50	50	50	50	50
SULFIDITY - (DAILY AVG.%)	28.4	29.5	28.7	28.7	30.0
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	38	36	39	39	40
Liquor Temp. (°F)	235	245	245	245	245
Backsweep (°)	-5 to-20	-5 to -20	-5 to -20	-5 to -20	-5 to -20
Sidesweep (°)	10L to 18R	10L to 18R	8L to 20R	8L to 20R	5L to 15R
COMBUSTION AIR TEMP (°F)	235	240	234	235	240
AIR FLOW					
Primary (M lbs/hr)	160	161	197	198	200
(% of Total)	38	39	54	54	52
Secondary (M lbs/hr)	197	196	115	113	126
(% of Total)	48	47	31	31	33
Tertiary (M lbs/hr)	58	59	55	55	56
(% of Total)	14	14	15	15	15
Total (M lbs/hr)	415	416	367	366	382
EXCESS O_2 (%)	2.0	2.0	2.4	2.4	2.8
TRS AVG. (ppm)	8.4	4.8	3.7	3.7	2.6
SO_2 AVG (ppm)	27.6	36.3	122.	122.	75.6
STEAM FLOW (M lbs/hr)	255	250	235	235	235
BOILER EXIT CONDITIONS					
Temp (°F)	633	678	672	655	673
ACFM (1000 cu.ft./min)	274	272	265	260	261
DSCFM(1000 cu.ft./min)	78.2	76.3	73.8	74.6	77.1
Grain Loading(gr/DSCF)	7.28	8.55	8.01	7.04	6.88
Particulate Load(lbs/hr)	4882	5592	5070	4495	4551
PRECIPITATOR INLET COND.					
Temp (°F)	435	440	420	420	425
ACFM(1000 cu.ft./min)	224	215	206	205	204
Volume @ 400°F	215	205	201	200	198
PRECIPITATOR OUTLET COND.					
Temp (°F)	414	417	400	400	415
ACFM (1000 cu.ft./min)	276	268	255	257	253
DSCF (1000 cu.ft./min)	102	102	97.9	99.1	101
Grain Loading(gr/DSCF)	.0796	.1256	.0380	.0486	.0600
Particulate Loading(lbs/hr)	69.9	109.9	32.0	41.2	52.1
PRECIPITATOR EFFICIENCY(%)	98.6	98.0	99.4	99.1	98.9

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	100	110	110	100	100
Air Distribution (1°/2°/3°-%)	55/30/15	55/30/15	55/30/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	4-26-73	4-27-73	4-27-73	4-30-73	4-30-73
SLUICE TANK LIQUOR					
Flow (gpm)	154	160	160	145	150
Density (lbs/gal)	11.2	11.3	11.3	11.1	11.2
Solids (%)	61.8	61.5	61.8	61.4	62.4
BOILER LOADING (%)	105	110	110	97	99
SALT CAKE (lbs/min)	50	50	50	45	45
SULFIDITY - (DAILY AVG.%)	30.0	29.9	29.9	30.7	30.7
NOZZLE CONDITIONS					
Size	40	40	40	38	38
Pressure (PSI)	40	40	40	38	38
Liquor Temp. (°F)	245	245	240	245	245
Backsweep (°)	-5 to -20	-5 to -20	-5 to -20	-6 to -19	-6 to -19
Sidesweep (°)	5L to 15R	5L to 15R	5L to 15R	10L to 15R	10L to 15R
COMBUSTION AIR TEMP (°F)	242	240	240	235	240
AIR FLOW					
Primary (M lbs/hr)	200	200	200	164	167
(% of Total)	52	53	53	44	44
Secondary (M lbs/hr)	126	120	120	148	147
(% of Total)	33	32	32	39	38
Tertiary (M lbs/hr)	56	56	56	63	63
(% of Total)	15	15	15	17	18
Total (M lbs/hr)	382	376	376	375	383
EXCESS O_2 (%)	2.8	2.0	2.0	2.2	2.2
TRS AVG. (ppm)	2.6	1.9	1.9	1.5	1.5
SO2 AVG (ppm)	75.6	51.5	51.5	128	128
STEAM FLOW (M lbs/hr)	235	240	245	235	250
BOILER EXIT CONDITIONS					
Temp (°F)	676	639	635	612	656
ACFM (1000 cu.ft./min)	271	270	277	263	268
DSCFM(1000 cu.ft./min)	79.9	79.4	82.3	74.3	73.2
Grain Loading(gr/DSCF)	5.54	7.18	7.23	7.29	6.95
Particulate Load(lbs/hr)	3797	4888	5104	5001	4699
PRECIPITATOR INLET COND.					
Temp (°F)	440	430	430	420	430
ACFM(1000 cu.ft./min)	214	219	225	216	214
Volume @ 400°F	204	212	218	211	206
PRECIPITATOR OUTLET COND.					
Temp (°F)	420	418	420	410	405
ACFM (1000 cu.ft./min)	274	269	274	250	265
DSCF (1000 cu.ft./min)	112.1	105.0	103.0	98.9	102.6
Grain Loading(gr/DSCF)	.0442	.0647	.0721	.0676	.0691
Particulate Loading(lbs/hr)	42.5	58.2	63.7	57.3	60.8
PRECIPITATOR EFFICIENCY(%)	99.0	98.9	98.8	98.9	98.7

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	3.5-4.5	0.5-1.5	0.5-1.5
TEST DATE	5-1-73	5-1-73	5-2-73	5-4-73	5-4-73
SLUICE TANK LIQUOR					
Flow (gpm)	151	159	152	151	153
Density (lbs/gal)	11.2	11.1	11.3	11.2	11.2
Solids (%)	61.6	61.1	62.3	60.1	60.6
BOILER LOADING (%)	103	101	106	100	102
SALT CAKE (lbs/min)	40	45	45	45	45
SULFIDITY - (DAILY AVG.%)	31.0	31.0	30.9	30.2	30.2
NOZZLE CONDITIONS					
Size	38	38	38	38	38
Pressure (PSI)	39	38	39	39	39
Liquor Temp. (°F)	245	245	242	245	248
Backsweep (°)	-5 to -20	-5 to -20	-5 to -20	-6 to -19	-6 to -19
Sidesweep (°)	10L to 15R	10L to 15R	20L to 20R	15L to 18R	15L to 18R
COMBUSTION AIR TEMP (°F)	235	235	235	245	245
AIR FLOW					
Primary (M lbs/hr)	166	166	181	150	155
(% of Total)	44	44	43	43	43
Secondary (M lbs/hr)	147	147	169	142	150
(% of Total)	39	39	40	41	42
Tertiary (M lbs/hr)	63	63	69	54	52
(% of Total)	17	17	17	16	15
Total (M lbs/hr)	376	376	419	346	357
EXCESS O_2 (%)	2.8	2.8	3.6	1.2	1.2
TRS AVG. (ppm)	1.7	1.7	4.1	58.4	58.4
SO2 AVG (ppm)	28.0	28.0	16.9	95.7	95.7
STEAM FLOW (M lbs/hr)	230	230	240	240	235
BOILER EXIT CONDITIONS					
Temp (°F)	684	685	613	605	595
ACFM (1000 cu.ft./min)	273	275	280	239	238
DSCFM(1000 cu.ft./min)	73.1	73.3	81.0	64.7	66.4
Grain Loading(gr/DSCF)	5.89	6.77	6.30	8.33	8.47
Particulate Load(lbs/hr)	3976	4585	4694	4565	4821
PRECIPITATOR INLET COND.					
Temp (°F)	430	430	410	385	385
ACFM(1000 cu.ft./min)	213	227	211	190	190
Volume @ 400°F	206	220	209	193	194
PRECIPITATOR OUTLET COND.					
Temp (°F)	410	425	400	370	365
ACFM (1000 cu.ft./min)	257	255	254	215	226
DSCF (1000 cu.ft./min)	99.8	98.0	102.0	82.0	86.4
Grain Loading(gr/DSCF)	.0945	.0796	.1567	.0555	.0365
Particulate Loading(lbs/hr)	80.9	66.9	137.0	39.0	27.0
PRECIPITATOR EFFICIENCY(%)	98.0	98.5	97.5	99.1	99.4

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	35/50/15	35/50/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	5-7-73	5-7-73	5-8-73	5-8-73	5-9-73
SLUICE TANK LIQUOR					
Flow (gpm)	155	154	155	155	142
Density (lbs/gal)	11.3	11.2	11.3	11.3	11.3
Solids (%)	60.7	62.6	61.1	61.2	62.1
BOILER LOADING (%)	105	106	106	106	98
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	29.2	29.2	30.0	30.0	30.9
NOZZLE CONDITIONS					
Size	38	38	38	38	38
Pressure (PSI)	38	38	37	37	41
Liquor Temp. (°F)	247	245	247	247	246
Backsweep (°)	-7 to -16	-7 to -16	-5 to -19	-5 to -19	-8 to -17
Sidesweep (°)	15L to 20R	15L to 20R	15L to 20R	15L to 20R	17L to 20R
COMBUSTION AIR TEMP (°F)	240	240	235	240	240
AIR FLOW					
Primary (M lbs/hr)	142	150	151	151	187
(% of Total)	36	36	36	36	53
Secondary (M lbs/hr)	195	203	200	200	111
(% of Total)	49	49	48	48	31
Tertiary (M lbs/hr)	60	61	68	67	56
(% of Total)	15	15	16	16	16
Total (M lbs/hr)	397	414	419	418	354
EXCESS O_2 (%)	2.0	2.0	2.4	2.4	2.6
TRS AVG. (ppm)	4.5	4.5	2.6	2.6	2.7
SO2 AVG (ppm)	23.9	23.9	42.5	42.5	91.6
STEAM FLOW (M lbs/hr)	235	240	240	245	225
BOILER EXIT CONDITIONS					
Temp (°F)	673	675	681	718	651
ACFM (1000 cu.ft./min)	260	269	277	286	257
DSCFM(1000 cu.ft./min)	73.6	76.4	77.6	76.8	74.6
Grain Loading(gr/DSCF)	8.25	8.48	8.01	10.32	5.88
Particulate Load(lbs/hr)	5200	5553	5325	6794	3761
PRECIPITATOR INLET COND.					
Temp (°F)	420	430	435	430	415
ACFM(1000 cu.ft./min)	203	211	217	216	202
Volume @ 400°F	199	203	209	209	199
PRECIPITATOR OUTLET COND.					
Temp (°F)	410	435	430	415	396
ACFM (1000 cu.ft./min)	267	272	270	275	244
DSCF (1000 cu.ft./min)	98.8	97.4	97.4	99.3	92.2
Grain Loading(gr/DSCF)	.0750	.0730	.1313	Data Missing	.0516
Particulate Loading(lbs/hr)	63.5	60.9	101.7	" "	40.8
PRECIPITATOR EFFICIENCY(%)	98.8	98.9	98.1	" "	98.9

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30		
Boiler Loading (% of Design)	100	100	100		
Air Distribution (1°/2°/3°-%)	55/30/15	55/30/15	55/30/15		
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0		
TEST DATE	5-9-73	5-11-73	5-11-73		
SLUICE TANK LIQUOR					
Flow (gpm)	142	146	146		
Density (lbs/gal)	11.2	11.3	11.4		
Solids (%)	60.8	61.2	61.2		
BOILER LOADING (%)	95	100	100		
SALT CAKE (lbs/min)	45	45	45		
SULFIDITY - (DAILY AVG.%)	30.9	29.9	29.9		
NOZZLE CONDITIONS					
Size	38	38	38		
Pressure (PSI)	41	42	42		
Liquor Temp. (°F)	245	248	250		
Backsweep (°)	-8 to -17	-5 to -20	-5 to -20		
Sidesweep (°)	17L to 20R	5L to 20R	5L to 20R		
COMBUSTION AIR TEMP (°F)	245	245	245		
AIR FLOW					
Primary (M lbs/hr)	187	186	186		
(% of Total)	53	54	53		
Secondary (M lbs/hr)	112	112	112		
(% of Total)	32	33	32		
Tertiary (M lbs/hr)	55	45	56		
(% of Total)	15	13	15		
Total (M lbs/hr)	354	343	354		
EXCESS O_2 (%)	2.6	2.5	2.5		
TRS AVG. (ppm)	2.7	1.0	1.0		
SO2 AVG (ppm)	91.6	11.4	11.4		
STEAM FLOW (M lbs/hr)	225	235	240		
BOILER EXIT CONDITIONS					
Temp (°F)	638	Data Missing	660		
ACFM (1000 cu.ft./min)	239	" "	242		
DSCFM(1000 cu.ft./min)	70.2	" "	73.0		
Grain Loading(gr/DSCF)	6.26	7.99	6.89		
Particulate Load(lbs/hr)	3768	4995	4308		
PRECIPITATOR INLET COND.					
Temp (°F)	415	410	415		
ACFM(1000 cu.ft./min)	191	Data Missing	189		
Volume @ 400°F	187	-	186		
PRECIPITATOR OUTLET COND.					
Temp (°F)	400	405	395		
ACFM (1000 cu.ft./min)	260	235	222		
DSCF (1000 cu.ft./min)	98.5	82.1	81.5		
Grain Loading(gr/DSCF)	.0583	.0724	.0622		
Particulate Loading(lbs/hr)	49.3	51.0	43.5		
PRECIPITATOR EFFICIENCY(%)	98.7	99.0	99.0		

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	.5-1.5
TEST DATE	5-29-73	5-29-73	5-30-73	7-17-73	6-20-73
SLUICE TANK LIQUOR					
Flow (gpm)	114	109	113	111	119
Density (lbs/gal)	11.2	11.2	11.3	11.3	11.4
Solids (%)	61.7	61.4	60.5	64.5	59.1
BOILER LOADING (%)	78	74	76	80	82
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	30.8	30.8	30.0	30.7	28.3
NOZZLE CONDITIONS					
Size	34	34	34	34	34
Pressure (PSI)	39	39	40	39	38
Liquor Temp. (°F)	245	245	245	250	246
Backsweep (°)	-5 to -20	-5 to -20	-5 to -20	-5 to -20	-5 to -18
Sidesweep (°)	10L to 20R	10L to 20R	10L to 20R	15L to 20R	10L to 20R
COMBUSTION AIR TEMP (°F)	250	255	250	245	250
AIR FLOW					
Primary (M lbs/hr)	135	135	136	138	120
(% of Total)	45	46	45	45	43
Secondary (M lbs/hr)	124	123	122	123	115
(% of Total)	42	41	41	40	42
Tertiary (M lbs/hr)	40	40	40	46	42
(% of Total)	13	13	13	15	15
Total (M lbs/hr)	299	298	298	307	277
EXCESS O_2 (%)	3.0	3.0	2.9	2.8	1.0
TRS AVG. (ppm)	0.8	0.8	2.4	0.9	5.4
SO_2 AVG (ppm)	1.4	1.4	51.4	28.9	329
STEAM FLOW (M lbs/hr)	190	190	175	190	190
BOILER EXIT CONDITIONS					
Temp (°F)	554	551	565	535	555
ACFM (1000 cu.ft./min)	183	173	203	200	177
DSCFM(1000 cu.ft./min)	59.4	55.8	64.2	65.7	52.0
Grain Loading(gr/DSCF)	6.12	6.69	5.75	7.01	5.25
Particulate Load(lbs/hr)	3120	3199	3166	3950	2521
PRECIPITATOR INLET COND.					
Temp (°F)	380	382	385	375	368
ACFM(1000 cu.ft./min)	152	144	167	167	145
Volume @ 400°F	156	147	170	172	150
PRECIPITATOR OUTLET COND.					
Temp (°F)	372	370	385	352	375
ACFM (1000 cu.ft./min)	194	199	202	208	187
DSCF (1000 cu.ft./min)	75.8	80.5	77.0	83.5	71.0
Grain Loading(gr/DSCF)	.0209	.0327	.0455	.0510	.0556
Particulate Loading(lbs/hr)	13.6	22.6	30.0	36.5	34.0
PRECIPITATOR EFFICIENCY(%)	99.6	99.3	99.1	99.1	98.7

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	35/50/15
Excess O_2 (%)	.5-1.5	.5-1.5	3.5-4.5	3.5-4.5	2.0-3.0
TEST DATE	6-25-73	6-25-73	6-26-73	6-26-73	6-27-73
SLUICE TANK LIQUOR					
Flow (gpm)	125	128	128	126	126
Density (lbs/gal)	11.3	11.1	11.2	11.3	11.2
Solids (%)	61.4	60.9	61.6	62.5	62.2
BOILER LOADING (%)	86	85	86	88	87
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	28.2	28.2	28.3	28.3	28.1
NOZZLE CONDITIONS					
Size	34	34	34	34	34
Pressure (PSI)	40	40	40	40	40
Liquor Temp. (°F)	250	250	250	250	250
Backsweep (°)	-5 to-20	-5 to-20	-5 to-20	-5 to-20	-7 to-20
Sidesweep (°)	10L to 15R	10L to 15R	10L to 15R	10L to 15R	12L to 18R
COMBUSTION AIR TEMP (°F)	242	245	236	239	238
AIR FLOW					
Primary (M lbs/hr)	139	140	154	160	117
(% of Total)	45	45	45	45	37
Secondary (M lbs/hr)	122	122	142	142	155
(% of Total)	40	40	40	40	49
Tertiary (M lbs/hr)	40	40	44	44	45
(% of Total)	15	15	15	15	14
Total (M lbs/hr)	301	302	340	340	317
EXCESS O_2 (%)	1.5	1.5	3.4	3.4	2.0
TRS AVG. (ppm)	16.7	16.7	9.8	9.8	18.7
SO_2 AVG (ppm)	206	206	191	191	242
STEAM FLOW (M lbs/hr)	207	205	207	205	190
BOILER EXIT CONDITIONS					
Temp (°F)	595	610	595	580	575
ACFM (1000 cu.ft./min)	211	217	237	238	189
DSCFM(1000 cu.ft./min)	62.7	62.6	73.5	59.4	59.0
Grain Loading(gr/DSCF)	6.02	6.02	5.50	6.65	4.23
Particulate Load(lbs/hr)	3241	3233	3466	4192	2145
PRECIPITATOR INLET COND.					
Temp (°F)	400	385	390	392	380
ACFM(1000 cu.ft./min)	172	171	191	195	153
Volume @ 400°F	172	174	193	197	157
PRECIPITATOR OUTLET COND.					
Temp (°F)	390	385	385	395	385
ACFM (1000 cu.ft./min)	196	212	232	243	209
DSCF (1000 cu.ft./min)	73.6	79.9	90.9	93.6	79.4
Grain Loading(gr/DSCF)	.0363	.0314	.0386	.0347	.0330
Particulate Loading(lbs/hr)	22.9	21.5	30.1	27.8	22.5
PRECIPITATOR EFFICIENCY(%)	99.3	99.3	99.1	99.3	99.0

COMPLETE EPA TEST DATA FOR 28-30% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	28-30	28-30	28-30	28-30	28-30
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	55/30/15	55/30/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	6-27-73	6-28-73	7-11-73	7-11-73	7-12-73
SLUICE TANK LIQUOR					
Flow (gpm)	125	127	122	118	128
Density (lbs/gal)	11.3	11.3	11.2	11.3	11.3
Solids (%)	62.2	60.9	61.0	62.8	62.3
BOILER LOADING (%)	87	86	82	83	89
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	28.1	30.3	28.1	28.1	27.6
NOZZLE CONDITIONS					
Size	34	34	34	34	34
Pressure (PSI)	40	40	41	40	40
Liquor Temp. (°F)	250	250	250	250	250
Backsweep (°)	-7 to-20	-7 to-20	-5 to -20	-5 to -20	-5 to -20
Sidesweep (°)	12L to 18R	10L to 18R	15L to 20R	15L to 20R	15L to 20R
COMBUSTION AIR TEMP (°F)	245	244	245	245	245
AIR FLOW					
Primary (M lbs/hr)	117	115	165	163	160
(% of Total)	37	37	53	53	53
Secondary (M lbs/hr)	155	153	100	100	100
(% of Total)	49	49	32	32	33
Tertiary (M lbs/hr)	45	44	47	47	42
(% of Total)	14	14	15	15	14
Total (M lbs/hr)	317	312	312	310	302
EXCESS O_2 (%)	2.0	1.9	3.0	3.0	2.1
TRS AVG. (ppm)	18.7	19.2	0.0	0.0	0.2
SO2 AVG (ppm)	242	223	50,9	50.9	35.8
STEAM FLOW (M lbs/hr)	201	190	200	190	212
BOILER EXIT CONDITIONS					
Temp (°F)	585	610	520	545	540
ACFM (1000 cu.ft./min)	213	212	188	204	201
DSCFM(1000 cu.ft./min)	65.7	63.1	63.7	66.5	63.7
Grain Loading(gr/DSCF)	6.33	6.40	6.22	5.59	7.24
Particulate Load(lbs/hr)	3568	3470	3399	3184	3956
PRECIPITATOR INLET COND.					
Temp (°F)	375	370	365	365	365
ACFM(1000 cu.ft./min)	170	164	158	167	166
Volume @ 400°F	176	170	165	175	173
PRECIPITATOR OUTLET COND.					
Temp (°F)	385	380	345	342	345
ACFM (1000 cu.ft./min)	206	205	197	197	217
DSCF (1000 cu.ft./min)	79.6	77.8	80.4	81.7	88.1
Grain Loading(gr/DSCF)	.0283	.0375	.0527	.0554	.0548
Particulate Loading(lbs/hr)	19.3	25.0	36.3	38.8	41.3
PRECIPITATOR EFFICIENCY(%)	99.5	99.3	98.9	98,8	99.0

Table 11

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	7-25-73	7-25-73	7-26-73	7-26-73	10-22-73
SLUICE TANK LIQUOR					
Flow (gpm)	157	157	152	149	143
Density (lbs/gal)	11.4	11.3	11.4	11.3	11.5
Solids (%)	63.9	63.0	65.0	64.3	64.8
BOILER LOADING (%)	117	113	114	110	107
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	32.4	32.4	32.1	32.1	32.2
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	39	39	41	41	37
Liquor Temp. (°F)	245	245	245	245	250
Backsweep (°)	-5 to -20	-5 to -20	-5 to -20	-6 to -19	-5 to -22
Sidesweep (°)	15L to 21R	15L to 21R	12L to 20R	12L to 20R	10L to 10R
COMBUSTION AIR TEMP (°F)	230	235	235	235	230
AIR FLOW					
Primary (M lbs/hr)	181	180	173	173	163
(% of Total)	46	46	45	44	44
Secondary (M lbs/hr)	165	163	165	166	150
(% of Total)	41	41	42	43	41
Tertiary (M lbs/hr)	52	52	51	51	57
(% of Total)	13	13	13	13	15
Total (M lbs/hr)	398	395	389	390	370
EXCESS O_2 (%)	2.2	2.2	2.2	2.2	2.0
TRS AVG. (ppm)	Data	Data	7.6	7.6	21
SO_2 AVG (ppm)	Missing	Missing	353	353	215
STEAM FLOW (M lbs/hr)	245	245	235	235	235
BOILER EXIT CONDITIONS					
Temp (°F)	645	642	610	595	625
ACFM (1000 cu.ft./min)	265	270	268	254	245
DSCFM(1000 cu.ft./min)	77.6	79.5	82.1	77.0	72.0
Grain Loading(gr/DSCF)	8.48	9.09	7.27	7.53	6.78
Particulate Load(lbs/hr)	5636	6195	5120	4965	4181
PRECIPITATOR INLET COND.					
Temp (°F)	410	410	405	405	430
ACFM(1000 cu.ft./min)	209	213	216	208	201
Volume @ 400°F	206	210	214	207	195
PRECIPITATOR OUTLET COND.					
Temp (°F)	388	393	385	387	395
ACFM (1000 cu.ft./min)	261	255	251	269	236
DSCF (1000 cu.ft./min)	102	98.5	98.8	105	92.3
Grain Loading(gr/DSCF)	.0728	.0908	.0798	.0762	.0634
Particulate Loading(lbs/hr)	64.1	76.6	67.6	69.0	50.2
PRECIPITATOR EFFICIENCY(%)	98.9	98.8	98.7	98.6	98.8

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	110	110	110	110	110
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	35/50/15
Excess O_2 (%)	3.5-4.5	3.5-4.5	0.5-1.5	0.5-1.5	2.0-3.0
TEST DATE	7-30-73	7-30-73	8-2-73	8-2-73	7-31-73
SLUICE TANK LIQUOR					
Flow (gpm)	160	153	159	159	153
Density (lbs/gal)	11.2	11.3	10.9	11.1	11.1
Solids (%)	62.3	62.2	59.4	60.1	60.3
BOILER LOADING (%)	113	109	105	108	105
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	32.1	32.1	32.7	32.7	31.1
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	41	39	40	40	41
Liquor Temp. (°F)	240	240	240	240	245
Backsweep (°)	-5 to-20	-5 to -20	-6 to -19	-6 to -19	-6 to -19
Sidesweep (°)	15L to 20R	15L to 20R	15L to 20R	15L to 20R	15L to 20R
COMBUSTION AIR TEMP (°F)	235	235	243	243	240
AIR FLOW					
Primary (M lbs/hr)	182	187	152	165	150
(% of Total)	45	46	43	44	40
Secondary (M lbs/hr)	170	167	150	153	174
(% of Total)	42	41	42	41	46
Tertiary (M lbs/hr)	51	55	54	56	52
(% of Total)	13	13	15	15	14
Total (M lbs/hr)	403	409	356	374	376
EXCESS O_2 (%)	3.2	3.2	0.8	0.8	2.1
TRS AVG. (ppm)	11.4	11.4	6.8	6.8	18.1
SO2 AVG (ppm)	39.6	39.6	280	280	455
STEAM FLOW (M lbs/hr)	235	235	240	240	220
BOILER EXIT CONDITIONS					
Temp (°F)	665	676	640	635	620
ACFM (1000 cu.ft./min)	262	278	237	275	247
DSCFM(1000 cu.ft./min)	76.6	82.0	76.0	80.5	75.5
Grain Loading(gr/DSCF)	6.67	7.08	7.47	Data Missing	6.41
Particulate Load(lbs/hr)	4382	4954	4864	Data Missing	4039
PRECIPITATOR INLET COND.					
Temp (°F)	425	420	420	425	415
ACFM(1000 cu.ft./min)	206	215	189	222	200
Volume @ 400°F	200	210	185	216	198
PRECIPITATOR OUTLET COND.					
Temp (°F)	403	410	385	407	391
ACFM (1000 cu.ft./min)	258	277	239	246	253
DSCF (1000 cu.ft./min)	99.8	109	92.7	93.3	97.9
Grain Loading(gr/DSCF)	.0760	.0765	.0909	.0881	.0613
Particulate Loading(lbs/hr)	65.0	71.8	72.3	70.4	51.4
PRECIPITATOR EFFICIENCY(%)	98.5	98.6	98.5	-	98.7

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	
Boiler Loading (% of Design)	110	100	100	100	
Air Distribution (1°/2°/3°-%)	35/50/15	45/40/15	45/40/15	45/40/15	
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	
TEST DATE	7-31-73	10-18-73	10-19-73	10-19-73	
SLUICE TANK LIQUOR					
Flow (gpm)	154	150	140	140	
Density (lbs/gal)	11.2	11.3	11.3	11.4	
Solids (%)	60.5	61.8	60.9	60.7	
BOILER LOADING (%)	106	98	98	98	
SALT CAKE (lbs/min)	45	46	38	38	
SULFIDITY - (DAILY AVG.%)	31.1	32.3	31.8	31.8	
NOZZLE CONDITIONS					
Size	40	40	40	40	
Pressure (PSI)	41	36	38	38	
Liquor Temp. (°F)	245	250	250	250	
Backsweep (°)	-6 to -19	-11 to -15	-11 to -15	-11 to -15	
Sidesweep (°)	15L to 20R	15L to 5R	15L to 5R	15L to 5R	
COMBUSTION AIR TEMP (°F)	242	235	244	244	
AIR FLOW					
Primary (M lbs/hr)	150	155	144	144	
(% of Total)	38	45	44	44	
Secondary (M lbs/hr)	190	135	137	137	
(% of Total)	48	40	41	41	
Tertiary (M lbs/hr)	53	52	50	50	
(% of Total)	14	15	15	15	
Total (M lbs/hr)	393	342	331	331	
EXCESS O_2 (%)	2.1	2.2	1.8	1.8	
TRS AVG. (ppm)	18	17	74	74	
SO_2 AVG (ppm)	455	295	433	433	
STEAM FLOW (M lbs/hr)	225	230	228	225	
BOILER EXIT CONDITIONS					
Temp (°F)	665	630	610	615	
ACFM (1000 cu.ft./min)	258	224	230	213	
DSCFM(1000 cu.ft./min)	72.6	66.5	66.2	61.4	
Grain Loading(gr/DSCF)	7.39	6.18	6.55	6.96	
Particulate Load(lbs/hr)	4600	3523	3720	3667	
PRECIPITATOR INLET COND.					
Temp (°F)	420	430	410	410	
ACFM(1000 cu.ft./min)	202	183	187	172	
Volume @ 400°F	198	177	185	170	
PRECIPITATOR OUTLET COND.					
Temp (°F)	400	380	361	360	
ACFM (1000 cu.ft./min)	244	234	215	213	
DSCF (1000 cu.ft./min)	94.1	97.4	87.7	82.8	
Grain Loading(gr/DSCF)	.0649	.0506	.0317	.0341	
Particulate Loading(lbs/hr)	52.4	42.2	23.9	24.2	
PRECIPITATOR EFFICIENCY(%)	98.9	98.8	99.4	99.3	

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	35/50/15
Excess O_2 (%)	0.5-1.5	0.5-1.5	3.5-4.5	3.5-4.5	2.0-3.0
TEST DATE	10-30-73	10-30-73	10-29-73	10-29-73	11-1-73
SLUICE TANK LIQUOR					
Flow (gpm)	145	140	150	150	147
Density (lbs/gal)	11.4	11.5	11.5	11.5	11.5
Solids (%)	61.4	63.6	63.9	63.5	64.8
BOILER LOADING (%)	108	105	107	105	104
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	33.4	33.4	33.4	33.4	32.5
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	38	38	40	40	37
Liquor Temp. (°F)	250	250	250	250	250
Backsweep (°)	-7 to -20	-7 to -20	-7 to -20	-7 to -20	-7 to -20
Sidesweep (°)	20L to 5R	20L to 5R	5L to 20R	5L to 20R	20L to 5R
COMBUSTION AIR TEMP (°F)	235	235	230	230	230
AIR FLOW					
Primary (M lbs/hr)	149	143	180	172	130
(% of Total)	43	42	45	45	35
Secondary (M lbs/hr)	149	145	160	152	180
(% of Total)	43	43	40	40	49
Tertiary (M lbs/hr)	51	50	64	61	56
(% of Total)	14	15	15	15	15
Total (M lbs/hr)	349	338	404	385	366
EXCESS O_2 (%)	2.0	2.0	3.6	3.6	2.6
TRS AVG. (ppm)	18.1	18.1	6.6	6.6	15.8
SO2 AVG (ppm)	77.4	77.4	151	151	215
STEAM FLOW (M lbs/hr)	230	225	225	230	230
BOILER EXIT CONDITIONS					
Temp (°F)	685	675	675	675	620
ACFM (1000 cu.ft./min)	225	204	250	253	233
DSCFM(1000 cu.ft./min)	62.0	55.3	73.8	72.5	69.5
Grain Loading(gr/DSCF)	7.71	8.08	6.38	6.56	6.72
Particulate Load(lbs/hr)	4102	3828	4031	4073	4007
PRECIPITATOR INLET COND.					
Temp (°F)	430	420	435	430	420
ACFM(1000 cu.ft./min)	175	157	197	198	190
Volume @ 400°F	169	154	190	192	186
PRECIPITATOR OUTLET COND.					
Temp (°F)	366	355	365	365	346
ACFM (1000 cu.ft./min)	209	208	233	232	227
DSCF (1000 cu.ft./min)	89.7	84.2	100	99.8	94.2
Grain Loading(gr/DSCF)	.0421	.0482	.0661	.0579	.0356
Particulate Loading(lbs/hr)	32.4	34.8	57.1	50.3	28.6
PRECIPITATOR EFFICIENCY(%)	99.2	99.1	98.6	98.8	99.3

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	100	100	100	100	100
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	55/30/15	55/30/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	11-1-73	11-2-73	11-5-73	11-5-73	11-6-73
SLUICE TANK LIQUOR					
Flow (gpm)	145	140	145	144	140
Density (lbs/gal)	11.4	11.4	11.4	11.4	11.4
Solids (%)	64.0	61.8	63.4	63.5	62.8
BOILER LOADING (%)	102	95	99	98	97
SALT CAKE (lbs/min)	45	45	45	45	45
SULFIDITY - (DAILY AVG.%)	32.5	32.7	31.4	31.4	31.1
NOZZLE CONDITIONS					
Size	40	40	40	40	40
Pressure (PSI)	37	38	40	40	40
Liquor Temp. (°F)	250	250	255	255	250
Backsweep (°)	-7 to -20	-5 to -20	-5 to -20	-6 to -20	-5 to -20
Sidesweep (°)	20L to 5R	15L to 10R	15L to 10R	15L to 10R	10L to 15R
COMBUSTION AIR TEMP (°F)	230	230	230	230	230
AIR FLOW					
Primary (M lbs/hr)	130	125	181	181	180
(% of Total)	36	36	55	55	55
Secondary (M lbs/hr)	180	175	97	97	100
(% of Total)	49	50	30	30	30
Tertiary (M lbs/hr)	56	50	50	50	50
(% of Total)	15	14	15	15	15
Total (M lbs/hr)	366	350	328	328	330
EXCESS O_2 (%)	2.6	2.6	2.6	2.6	3.0
TRS AVG. (ppm)	15.8	23.8	Data	Data	6.3
SO_2 AVG (ppm)	215	255	Missing	Missing	291
STEAM FLOW (M lbs/hr)	235	220	220	220	218
BOILER EXIT CONDITIONS					
Temp (°F)	595	615	635	635	620
ACFM (1000 cu.ft./min)	235	224	231	235	228
DSCFM(1000 cu.ft./min)	70.4	66.5	68.5	69.1	66.0
Grain Loading(gr/DSCF)	6.52	6.38	8.72	6.89	4.53
Particulate Load(lbs/hr)	3931	3639	5120	5163	2640
PRECIPITATOR INLET COND.					
Temp (°F)	415	415	425	425	460
ACFM(1000 cu.ft./min)	195	182	186	190	194
Volume @ 400°F	192	179	181	185	181
PRECIPITATOR OUTLET COND.					
Temp (°F)	354	344	363	361	370
ACFM (1000 cu.ft./min)	223	221	236	235	226
DSCF (1000 cu.ft./min)	90.6	92.8	96.2	95.6	91.2
Grain Loading(gr/DSCF)	.0354	.0320	.0496	.0678	.0577
Particulate Loading(lbs/hr)	27.5	25.5	40.9	55.5	45.2
PRECIPITATOR EFFICIENCY(%)	99.3	99.3	99.6	98.9	98.3

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	100	100	75	75	75
Air Distribution (1°/2°/3°-%)	55/30/15	55/30/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	8-6-73	8-6-73	10-23-73	10-23-73	10-24-73
SLUICE TANK LIQUOR					
Flow (gpm)	137	136	120	120	122
Density (lbs/gal)	11.0	11.4	11.3	11.4	11.4
Solids (%)	60.1	62.7	63.6	64.1	62.5
BOILER LOADING (%)	92	99	84	85	85
SALT CAKE (lbs/min)	40	45	40	40	40
SULFIDITY - (DAILY AVG.%)	32.6	32.6	32.0	32.0	32.1
NOZZLE CONDITIONS					
Size	38	38	34	34	34
Pressure (PSI)	40	40	40	40	40
Liquor Temp. (°F)	247	247	250	250	250
Backsweep (°)	-5 to -20	-5 to -20	-8 to -18	-8 to -18	-7 to -20
Sidesweep (°)	15L to 20R	15L to 20R	20L to 5R	20L to 5R	20L to 5R
COMBUSTION AIR TEMP (°F)	235	240	245	245	245
AIR FLOW					
Primary (M lbs/hr)	185	180	126	126	130
(% of Total)	54	53	45	45	45
Secondary (M lbs/hr)	112	112	115	115	117
(% of Total)	33	33	41	41	41
Tertiary (M lbs/hr)	45	46	38	38	40
(% of Total)	13	14	14	14	14
Total (M lbs/hr)	342	338	279	279	287
EXCESS O_2 (%)	2.4	2.4	2.2	2.2	2.4
TRS AVG. (ppm)	Data	Data	17	17	13
SO2 AVG (ppm)	Missing	Missing	480	480	464
STEAM FLOW (M lbs/hr)	225	225	185	190	180
BOILER EXIT CONDITIONS					
Temp (°F)	599	617	565	560	595
ACFM (1000 cu.ft./min)	237	236	189	181	207
DSCFM(1000 cu.ft./min)	66.7	65.2	59.6	58.2	59.2
Grain Loading(gr/DSCF)	5.94	6.78	4.04	5.15	6.02
Particulate Load(lbs/hr)	3660	4086	2061	2573	3053
PRECIPITATOR INLET COND.					
Temp (°F)	390	395	390	390	395
ACFM(1000 cu.ft./min)	190	187	156	151	167
Volume @ 400°F	192	188	158	153	168
PRECIPITATOR OUTLET COND.					
Temp (°F)	368	373	330	330	335
ACFM (1000 cu.ft./min)	232	231	160	178	185
DSCF (1000 cu.ft./min)	92.2	92.0	66.3	72.5	76.3
Grain Loading(gr/DSCF)	.0520	.1117	.0820	.0329	.0237
Particulate Loading(lbs/hr)	41.1	88.1	46.6	20.4	15.5
PRECIPITATOR EFFICIENCY(%)	98.9	97.8	97.7	99.2	99.5

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	35/50/15
Excess O_2 (%)	2.0-3.0	0.5-1.5	0.5-1.5	3.5-4.5	2.0-3.0
TEST DATE	10-24-73	10-25-73	10-25-73	11-10-73	11-9-73
SLUICE TANK LIQUOR					
Flow (gpm)	125	125	125	120	120
Density (lbs/gal)	11.4	11.5	11.5	11.3	11.5
Solids (%)	62.2	62.9	63.7	63.2	64.0
BOILER LOADING (%)	85	89	91	81	85
SALT CAKE (lbs/min)	40	40	40	40	40
SULFIDITY - (DAILY AVG.%)	32.1	32.7	32.7	32.6	31.6
NOZZLE CONDITIONS					
Size	34	34	34	34	34
Pressure (PSI)	40	40	40	40	40
Liquor Temp. (°F)	250	250	250	250	255
Backsweep (°)	-7 to -20	-6 to -20	-6 to -20	-5 to -20	-5 to -20
Sidesweep (°)	20L to 5R	20L to 5R	20L to 5R	15L to 15R	10L to 20R
COMBUSTION AIR TEMP (°F)	250	250	250	244	240
AIR FLOW					
Primary (M lbs/hr)	132	122	125	136	122
(% of Total)	46	45	45	45	39
Secondary (M lbs/hr)	117	114	115	125	150
(% of Total)	40	41	42	41	47
Tertiary (M lbs/hr)	41	37	37	44	43
(% of Total)	14	14	13	14	14
Total (M lbs/hr)	290	273	277	305	315
EXCESS O_2 (%)	2.4	0.7	0.7	3.0	2.3
TRS AVG. (ppm)	13	45	45	4.7	3.0
SO2 AVG (ppm)	464	352	352	124	47
STEAM FLOW (M lbs/hr)	180	190	200	210	205
BOILER EXIT CONDITIONS					
Temp (°F)	595	595	580	545	505
ACFM (1000 cu.ft./min)	211	186	202	186	169
DSCFM(1000 cu.ft./min)	62.0	54.3	60.0	60.9	57.4
Grain Loading(gr/DSCF)	5.87	6.65	6.41	6.33	6.39
Particulate Load(lbs/hr)	3119	3094	3300	3302	3142
PRECIPITATOR INLET COND.					
Temp (°F)	395	380	385	373	365
ACFM(1000 cu.ft./min)	171	148	164	154	145
Volume @ 400°F	172	151	167	159	151
PRECIPITATOR OUTLET COND.					
Temp (°F)	332	335	335	310	290
ACFM (1000 cu.ft./min)	199	183	196	177	180
DSCF (1000 cu.ft./min)	80.9	76.0	73.9	75.5	79.3
Grain Loading(gr/DSCF)	.0275	.0431	.0253	.0252	.0485
Particulate Loading(lbs/hr)	19.1	28.0	17.3	16.3	33.0
PRECIPITATOR EFFICIENCY(%)	99.4	99.1	99.5	99.5	99.0

COMPLETE EPA TEST DATA FOR 31-33% SULFIDITY RANGE

TARGET CONDITIONS					
Sulfidity (%)	31-33	31-33	31-33	31-33	31-33
Boiler Loading (% of Design)	75	75	75	75	75
Air Distribution (1°/2°/3°-%)	35/50/15	35/50/15	55/30/15	55/30/15	55/30/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	11-9-73	11-2-73	11-6-73	11-7-73	11-7-73
SLUICE TANK LIQUOR					
Flow (gpm)	122	120	140	120	120
Density (lbs/gal)	11.4	10.9	11.6	11.5	11.5
Solids (%)	64.2	61.8	64.6	65.9	65.5
BOILER LOADING (%)	84	77	79	88	87
SALT CAKE (lbs/min)	40	40	45	40	40
SULFIDITY - (DAILY AVG.%)	31.6	32.7	31.1	30.9	30.9
NOZZLE CONDITIONS					
Size	34	34	34	40	40
Pressure (PSI)	40	40	40	40	40
Liquor Temp. (°F)	255	250	250	250	250
Backsweep (°)	-5 to -20	-5 to -20	-5 to -20	-5 to -20	-5 to -20
Sidesweep (°)	10L to 20R	15L to 10R	10L to 15R	10L to 15R	10L to 15R
COMBUSTION AIR TEMP (°F)	240	240	250	240	240
AIR FLOW					
Primary (M lbs/hr)	122	110	140	145	145
(% of Total)	39	37	55	55	54
Secondary (M lbs/hr)	150	142	75	80	80
(% of Total)	47	48	30	30	30
Tertiary (M lbs/hr)	43	43	38	38	42
(% of Total)	14	15	15	15	16
Total (M lbs/hr)	315	295	254	263	267
EXCESS O_2 (%)	2.3	3.0	3.0	2.3	2.3
TRS AVG. (ppm)	3.0	21.6	14.4	14.2	14.2
SO2 AVG (ppm)	47	260	335	117	117
STEAM FLOW (M lbs/hr)	210	190	177	200	200
BOILER EXIT CONDITIONS					
Temp (°F)	515	585	555	595	580
ACFM (1000 cu.ft./min)	185	178	168	187	199
DSCFM(1000 cu.ft./min)	61.7	53.8	53.1	57.0	61.5
Grain Loading(gr/DSCF)	5.83	6.10	5.19	6.57	6.07
Particulate Load(lbs/hr)	3081	2811	2363	3212	3203
PRECIPITATOR INLET COND.					
Temp (°F)	365	390	380	395	395
ACFM(1000 cu.ft./min)	157	145	139	152	164
Volume @ 400°F	163	146	142	153	165
PRECIPITATOR OUTLET COND.					
Temp (°F)	291	326	335	326	335
ACFM (1000 cu.ft./min)	177	185	176	170	184
DSCF (1000 cu.ft./min)	77.3	78.5	72.9	72.6	77.1
Grain Loading(gr/DSCF)	.0277	.0228	.0260	.0270	.0271
Particulate Loading(lbs/hr)	18.3	15.4	16.2	16.8	17.9
PRECIPITATOR EFFICIENCY(%)	99.4	99.5	99.3	99.5	99.4

Table 12

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	High Black Liquor Solids (65%)				
Boiler Loading (% of Design)	100	100	100	100	
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	
TEST DATE	1/22/74	1/22/74	1/23/74	1/23/74	
SLUICE TANK LIQUOR					
Flow (gpm)	133	132	132	131	
Density (lbs/gal)	11.5	11.6	11.5	11.5	
Solids (%)	65.5	65.9	64.6	64.7	
BOILER LOADING (%)	102	102	100	99	
SALT CAKE (lbs/min)	30	30	30	30	
SULFIDITY - (DAILY AVG.%)	28.9	28.9	28.9	28.9	
NOZZLE CONDITIONS					
Size	40	40	40	40	
Pressure (PSI)	40	40	40	40	
Liquor Temp. (°F)	250	250	250	250	
Backsweep (°)	-5 to -20	-5 to -20	-8 to -17	-8 to -17	
Sidesweep (°)	8L to 8R	8L to 8R	7L to 10R	7L to 10R	
COMBUSTION AIR TEMP (°F)	235	235	235	235	
AIR FLOW					
Primary (M lbs/hr)	150	150	150	150	
(% of Total)	45	45	45	45	
Secondary (M lbs/hr)	135	135	136	317	
(% of Total)	40	40	40	41	
Tertiary (M lbs/hr)	52	52	50	50	
(% of Total)	15	15	15	14	
Total (M lbs/hr)	337	337	336	337	
EXCESS O_2 (%)	2.0	2.1	2.3	2.6	
TRS AVG. (ppm)	0.4	0.4	Data	Data	
SO2 AVG (ppm)	0	0	Missing	Missing	
STEAM FLOW (M lbs/hr)	227	221	216	199	
BOILER EXIT CONDITIONS					
Temp (°F)	570	605	580	635	
ACFM (1000 cu.ft./min)	211	200	203	206	
DSCFM(1000 cu.ft./min)	64.2	60.7	63.3	60.7	
Grain Loading(gr/DSCF)	8.35	6.25	7.54	7.33	
Particulate Load(lbs/hr)	4599	3252	4090	3817	
PRECIPITATOR INLET COND.					
Temp (°F)	365	370	370	390	
ACFM(1000 cu.ft./min)	169	132	162	160	
Volume @ 400°F	176	137	168	161	
PRECIPITATOR OUTLET COND.					
Temp (°F)	375	370	365	370	
ACFM (1000 cu.ft./min)	213	212	189	181	
DSCF (1000 cu.ft./min)	84.7	80.2	76.0	72.5	
Grain Loading(gr/DSCF)	0.0829	0.0533	0.0486	0.0411	
Particulate Loading(lbs/hr)	60.2	41.2	31.6	25.5	
PRECIPITATOR EFFICIENCY(%)	98.7	98.7	99.2	99.3	

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Low Black Liquor Solids (58%)			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	1/24/74	1/24/74	1/25/74	1/25/74
SLUICE TANK LIQUOR				
Flow (gpm)	141	139	137	138
Density (lbs/gal)	11.1	11.1	11.1	11.3
Solids (%)	57.8	58.3	56.8	61.4
BOILER LOADING (%)	92	91	87	98
SALT CAKE (lbs/min)	30	30	30	30
SULFIDITY - (DAILY AVG.%)	27.4	27.4	28.3	28.3
NOZZLE CONDITIONS				
Size	40	40	40	40
Pressure (PSI)	43	43	44	44
Liquor Temp. (°F)	235	235	245	250
Backsweep (°)	-6 to -19	-6 to -19	-6 to -19	-6 to -19
Sidesweep (°)	8L to 8 R	8 L to 8 R	5L to 10R	5L to 10R
COMBUSTION AIR TEMP (°F)	235	235	235	235
AIR FLOW				
Primary (M lbs/hr)	150	150	145	145
(% of Total)	45	45	45	46
Secondary (M lbs/hr)	135	135	125	125
(% of Total)	40	40	40	40
Tertiary (M lbs/hr)	50	50	46	45
(% of Total)	15	15	15	14
Total (M lbs/hr)	335	335	316	315
EXCESS O_2 (%)	3.0	3.2	3.1	1.3
TRS AVG. (ppm)	0.3	0.3	Data	4
SO2 AVG (ppm)	4	9	Missing	1
STEAM FLOW (M lbs/hr)	199	195	189	209
BOILER EXIT CONDITIONS				
Temp (°F)	585	595	570	585
ACFM (1000 cu.ft./min)	202	205	197	204
DSCFM(1000 cu.ft./min)	61.8	62.0	59.3	59.8
Grain Loading(gr/DSCF)	5.59	5.17	4.68	7.65
Particulate Load(lbs/hr)	2961	2749	2378	4226
PRECIPITATOR INLET COND.				
Temp (°F)	390	390	360	380
ACFM(1000 cu.ft./min)	164	166	156	164
Volume @ 400°F	166	167	164	168
PRECIPITATOR OUTLET COND.				
Temp (°F)	370	375	365	370
ACFM (1000 cu.ft./min)	181	185	211	215
DSCF (1000 cu.ft./min)	71.0	72.0	80.3	81.0
Grain Loading(gr/DSCF)	0.0511	0.0552	0.0366	0.0465
Particulate Loading(lbs/hr)	31.2	34.0	25.2	32.3
PRECIPITATOR EFFICIENCY(%)	99.0	98.8	98.9	99.2

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Low Black Liquor Temperature (220°F.)			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	1/31/74	1/31/74	2/1/74	2/1/74
SLUICE TANK LIQUOR				
Flow (gpm)	143	141	141	142
Density (lbs/gal)	11.5	11.4	11.4	11.4
Solids (%)	62.9	63.3	62.0	62.4
BOILER LOADING (%)	105	103	102	103
SALT CAKE (lbs/min)	15	15	15	15
SULFIDITY - (DAILY AVG.%)	27.4	27.4	27.0	27.0
NOZZLE CONDITIONS				
Size	40	40	40	40
Pressure (PSI)	38	36	38	38
Liquor Temp. (°F)	220	220	223	223
Backsweep (°)	-8 to -17	-8 to -17	-7 to -19	-7 to -19
Sidesweep (°)	8L to 10R	8L to 10R	8L to 10R	8L to 10R
COMBUSTION AIR TEMP (°F)	225	225	230	230
AIR FLOW				
Primary (M lbs/hr)	160	160	160	160
(% of Total)	45	45	45	45
Secondary (M lbs/hr)	145	145	145	145
(% of Total)	40	40	40	40
Tertiary (M lbs/hr)	53	53	53	53
(% of Total)	15	15	15	15
Total (M lbs/hr)	358	358	358	358
EXCESS O_2 (%)	1.8	1.7	2.1	2.0
TRS AVG. (ppm)	14	Data Missing	1	0
SO2 AVG (ppm)	0		2	7
STEAM FLOW (M lbs/hr)	236	231	224	230
BOILER EXIT CONDITIONS				
Temp (°F)	565	620	585	560
ACFM (1000 cu.ft./min)	214	214	228	184
DSCFM(1000 cu.ft./min)	67.0	61.9	70.7	58.8
Grain Loading(gr/DSCF)	7.88	8.33	7.27	6.40
Particulate Load(lbs/hr)	4518	4421	4408	3224
PRECIPITATOR INLET COND.				
Temp (°F)	385	390	385	385
ACFM(1000 cu.ft./min)	161	169	185	153
Volume @ 400°F	163	171	188	155
PRECIPITATOR OUTLET COND.				
Temp (°F)	370	365	375	375
ACFM (1000 cu.ft./min)	230	228	230	229
DSCF (1000 cu.ft./min)	91.2	86.9	90.4	90.0
Grain Loading(gr/DSCF)	0.0410	0.0489	0.0458	0.0389
Particulate Loading(lbs/hr)	32.1	36.4	35.6	30.0
PRECIPITATOR EFFICIENCY(%)	99.3	99.2	99.2	99.1

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Nozzle Size (36) vs. Nozzle Pressure			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	11/14/73	11/14/73	1/29/74	1/29/74
SLUICE TANK LIQUOR				
Flow (gpm)	140	140	122	121
Density (lbs/gal)	11.4	11.4	11.5	11.5
Solids (%)	62.6	62.5	63.8	63.8
BOILER LOADING (%)	101	101	91	90
SALT CAKE (lbs/min)	45	45	15	15
SULFIDITY - (DAILY AVG.%)	29.9	29.9	26.8	26.8
NOZZLE CONDITIONS				
Size	36	36	36	36
Pressure (PSI)	45	45	39	38
Liquor Temp. (°F)	250	250	250	250
Backsweep (°)	-8 to -17	-8 to -17	-5 to -20	-5 to -20
Sidesweep (°)	15L to 5R	15L to 5R	12L to 5R	12L to 5R
COMBUSTION AIR TEMP (°F)	245	245	240	240
AIR FLOW				
Primary (M lbs/hr)	146	140	148	148
(% of Total)	45	46	45	44
Secondary (M lbs/hr)	128	122	134	135
(% of Total)	40	40	40	41
Tertiary (M lbs/hr)	50	44	49	50
(% of Total)	15	14	15	15
Total (M lbs/hr)	324	306	331	333
EXCESS O_2 (%)	2.7	2.3	2.4	2.0
TRS AVG. (ppm)	4	26	3	1
SO2 AVG (ppm)	24	123	0	0
STEAM FLOW (M lbs/hr)	221	217	205	204
BOILER EXIT CONDITIONS				
Temp (°F)	565	580	565	565
ACFM (1000 cu.ft./min)	194	179	198	208
DSCFM(1000 cu.ft./min)	59.6	52.8	62.5	65.1
Grain Loading(gr/DSCF)	7.78	7.42	7.07	7.56
Particulate Load(lbs/hr)	3977	3361	3785	4218
PRECIPITATOR INLET COND.				
Temp (°F)	390	390	380	380
ACFM(1000 cu.ft./min)	161	146	162	170
Volume @ 400°F	163	148	166	174
PRECIPITATOR OUTLET COND.				
Temp (°F)	333	328	360	365
ACFM (1000 cu.ft./min)	194	185	206	209
DSCF (1000 cu.ft./min)	76.6	71.7	82.6	82.1
Grain Loading(gr/DSCF)	0.0510	0.0489	0.0300	0.0281
Particulate Loading(lbs/hr)	33.4	30.1	21.2	19.8
PRECIPITATOR EFFICIENCY(%)	99.2	99.1	99.4	99.5

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Nozzle Size (32-38) vs. Nozzle Pressure			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	1/30/74	1/30/74	11/15/73	11/15/73
SLUICE TANK LIQUOR				
Flow (gpm)	120	120	144	129
Density (lbs/gal)	11.5	11.5	11.1	11.3
Solids (%)	64.6	64.6	62.5	62.4
BOILER LOADING (%)	90	90	90	92
SALT CAKE (lbs/min)	15	15	45	45
SULFIDITY - (DAILY AVG.%)	28.1	28.1	30.7	30.7
NOZZLE CONDITIONS				
Size	32	32	38	38
Pressure (PSI)	48	48	42	42
Liquor Temp. (°F)	248	248	250	250
Backsweep (°)	-7 to -18	-7 to -18	-7 to -18	-7 to -18
Sidesweep (°)	15L to 0R	15L to 0R	15L to 5R	15L to 5R
COMBUSTION AIR TEMP (°F)	235	235	245	245
AIR FLOW				
Primary (M lbs/hr)	142	142	135	130
(% of Total)	45	45	45	44
Secondary (M lbs/hr)	128	128	122	118
(% of Total)	40	40	40	40
Tertiary (M lbs/hr)	48	48	46	46
(% of Total)	15	15	15	16
Total (M lbs/hr)	318	318	303	294
EXCESS O_2 (%)	2.5	3.5	1.5	2.1
TRS AVG. (ppm)	1	Data	20	29
SO_2 AVG (ppm)	1	Missing	163	75
STEAM FLOW (M lbs/hr)	200	199	211	209
BOILER EXIT CONDITIONS				
Temp (°F)	510	545	570	580
ACFM (1000 cu.ft./min)	189	213	183	161
DSCFM(1000 cu.ft./min)	64.4	70.6	54.5	48.8
Grain Loading(gr/DSCF)	7.10	6.62	7.35	4.24
Particulate Load(lbs/hr)	3922	4004	3432	1773
PRECIPITATOR INLET COND.				
Temp (°F)	365	370	390	380
ACFM(1000 cu.ft./min)	161	176	151	131
Volume @ 400°F	168	182	153	133
PRECIPITATOR OUTLET COND.				
Temp (°F)	350	360	327	323
ACFM (1000 cu.ft./min)	194	224	198	180
DSCF (1000 cu.ft./min)	79.6	93.1	76.0	70.1
Grain Loading(gr/DSCF)	0.0283	0.0152	0.0455	0.0466
Particulate Loading(lbs/hr)	19.3	12.1	29.7	28.0
PRECIPITATOR EFFICIENCY(%)	99.5	99.7	99.1	98.4

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Nozzle Size (40) vs. Nozzle Pressure				
Boiler Loading (% of Design)	100	100	100	100	
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15	
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	
TEST DATE	11/16/73	11/16/73	1/28/74	1/28/74	
SLUICE TANK LIQUOR					
Flow (gpm)	142	143	119	122	
Density (lbs/gal)	11.2	11.2	11.4	11.4	
Solids (%)	59.3	59.5	63.7	63.7	
BOILER LOADING (%)	89	89	88	90	
SALT CAKE (lbs/min)	45	45	15	15	
SULFIDITY - (DAILY AVG.%)	30.2	30.2	26.8	26.8	
NOZZLE CONDITIONS					
Size	40	40	40	40	
Pressure (PSI)	35	36	35	35	
Liquor Temp. (°F)	250	250	245	245	
Backsweep (°)	-7 to -18	-7 to -18	-6 to -19	-6 to -19	
Sidesweep (°)	15 L to 5R	15L to 5R	10L to 10R	10L to 10R	
COMBUSTION AIR TEMP (°F)	250	245	235	240	
AIR FLOW					
Primary (M lbs/hr)	140	146	145	135	
(% of Total)	44	45	46	44	
Secondary (M lbs/hr)	130	130	125	125	
(% of Total)	41	40	40	41	
Tertiary (M lbs/hr)	48	48	46	46	
(% of Total)	15	15	14	15	
Total (M lbs/hr)	318	324	316	306	
EXCESS O_2 (%)	2.5	1.5	2.9	2.6	
TRS AVG. (ppm)	14	9	0	0	
SO_2 AVG (ppm)	126	133	3	3	
STEAM FLOW (M lbs/hr)	215	210	196	201	
BOILER EXIT CONDITIONS					
Temp (°F)	605	610	570	600	
ACFM (1000 cu.ft./min)	199	199	176	190	
DSCFM(1000 cu.ft./min)	59.0	57.2	54.3	58.6	
Grain Loading(gr/DSCF)	6.84	7.26	7.93	6.96	
Particulate Load(lbs/hr)	3462	3560	3696	3498	
PRECIPITATOR INLET COND.					
Temp (°F)	405	400	375	375	
ACFM(1000 cu.ft./min)	162	160	143	150	
Volume @ 400°F	160	160	147	154	
PRECIPITATOR OUTLET COND.					
Temp (°F)	340	346	370	365	
ACFM (1000 cu.ft./min)	188	205	198	187	
DSCF (1000 cu.ft./min)	73.7	78.9	78.6	73.7	
Grain Loading(gr/DSCF)	0.0488	0.0471	0.0306	0.0326	
Particulate Loading(lbs/hr)	30.8	31.8	20.7	19.2	
PRECIPITATOR EFFICIENCY(%)	99.1	99.1	99.4	99.5	

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

	Investigation of Windbox Pressure Variations				
TARGET CONDITIONS	Low Secondary P(4"H_2O)			Low Secondary P(4"H_2O) Low Tertiary P(4"H_2O)	
Boiler Loading (% of Design)	100	100		100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15		45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0		2.0-3.0	2.0-3.0
TEST DATE	2/7/74	2/7/74		2/6/74	2/6/74
SLUICE TANK LIQUOR					
Flow (gpm)	142	143		137	140
Density (lbs/gal)	11.4	11.4		11.4	11.4
Solids (%)	62.0	62.8		62.8	62.8
BOILER LOADING (%)	102	105		100	102
SALT CAKE (lbs/min)	15	15		15	15
SULFIDITY - (DAILY AVG.%)	26.7	26.7		27.2	27.2
NOZZLE CONDITIONS					
Size	40	40		40	40
Pressure (PSI)	43	43		42	42
Liquor Temp. (°F)	250	250		250	250
Backsweep (°)	-6 to-21	-6 to -21		-6 to -21	-6 to -21
Sidesweep (°)	10L to 10R	10L to 10R		10L to 10R	10L to 10R
COMBUSTION AIR TEMP (°F)	225	225		225	225
AIR FLOW					
Primary (M lbs/hr)	150	150		150	150
(% of Total)	44	44		47	47
Secondary (M lbs/hr)	137	137		125	125
(% of Total)	41	41		39	39
Tertiary (M lbs/hr)	50	50		45	45
(% of Total)	15	15		14	14
Total (M lbs/hr)	337	337		325	325
EXCESS O_2 (%)	1.9	1.8		1.4	1.7
TRS AVG. (ppm)	2	2		2	4
SO_2 AVG (ppm)	1	3		15	25
STEAM FLOW (M lbs/hr)	220	218		217	217
BOILER EXIT CONDITIONS					
Temp (°F)	635	630		630	640
ACFM (1000 cu.ft./min)	218	218		222	213
DSCFM(1000 cu.ft./min)	65.7	65.5		67.4	62.9
Grain Loading(gr/DSCF)	7.69	7.39		7.91	7.59
Particulate Load(lbs/hr)	4328	4148		4569	4093
PRECIPITATOR INLET COND.					
Temp (°F)	393	390		385	385
ACFM(1000 cu.ft./min)	170	170		172	164
Volume @ 400°F	171	172		175	167
PRECIPITATOR OUTLET COND.					
Temp (°F)	370	378		370	370
ACFM (1000 cu.ft./min)	192	198		203	198
DSCF (1000 cu.ft./min)	78.6	78.4		81.5	79.0
Grain Loading(gr/DSCF)	0.0417	0.0624		0.0593	0.0491
Particulate Loading(lbs/hr)	28.1	41.9		41.4	33.2
PRECIPITATOR EFFICIENCY(%)	99.4	99.0		99.1	99.2

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Investigation of Windbox Pressure Variations Low Tertiary Windbox Pressure (4" H_2O)			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	2/4/74	2/4/74	2/5/74	2/5/74
SLUICE TANK LIQUOR				
Flow (gpm)	130	132	134	131
Density (lbs/gal)	11.4	11.5	11.4	11.3
Solids (%)	61.5	62.8	61.6	61.4
BOILER LOADING (%)	92	97	96	93
SALT CAKE (lbs/min)	15	15	15	15
SULFIDITY - (DAILY AVG.%)	27.4	27.4	27.6	27.6
NOZZLE CONDITIONS				
Size	40	40	40	40
Pressure (PSI)	38	38	40	40
Liquor Temp. (°F)	250	250	250	250
Backsweep (°)	-5 to -20	-6 to -21	-6 to -21	-6 to -21
Sidesweep (°)	10L to 10R	10L to 10R	10L to 10R	10L to 10R
COMBUSTION AIR TEMP (°F)	227	228	225	225
AIR FLOW				
Primary (M lbs/hr)	153	153	150	153
(% of Total)	45	45	44	45
Secondary (M lbs/hr)	140	141	142	143
(% of Total)	41	41	42	42
Tertiary (M lbs/hr)	48	47	48	47
(% of Total)	14	14	14	13
Total (M lbs/hr)	341	341	340	343
EXCESS O_2 (%)	3.0	3.0	2.2	3.0
TRS AVG. (ppm)	1	1	2	2
SO2 AVG (ppm)	2	3	3	5
STEAM FLOW (M lbs/hr)	208	207	206	210
BOILER EXIT CONDITIONS				
Temp (°F)	605	620	620	640
ACFM (1000 cu.ft./min)	210	218	211	207
DSCFM(1000 cu.ft./min)	64.4	66.1	64.8	63.0
Grain Loading(gr/DSCF)	7.83	7.35	6.63	6.37
Particulate Load(lbs/hr)	4654	4487	3681	3439
PRECIPITATOR INLET COND.				
Temp (°F)	380	385	380	387
ACFM(1000 cu.ft./min)	166	170	164	159
Volume @ 400°F	170	173	168	162
PRECIPITATOR OUTLET COND.				
Temp (°F)	380	380	360	375
ACFM (1000 cu.ft./min)	217	207	184	207
DSCF (1000 cu.ft./min)	86.6	81.4	74.4	86.4
Grain Loading(gr/DSCF)	0.0368	0.0279	0.0494	0.0678
Particulate Loading(lbs/hr)	27.4	19.5	31.5	50.1
PRECIPITATOR EFFICIENCY(%)	99.4	99.6	99.2	98.5

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Investigation of Salt Cake Addition Rates			
Boiler Loading (% of Design)	100	100	100	100
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15	45/40/15	45/40/15
Excess O_2 (%)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
TEST DATE	2/11/74	2/11/74	2/12/74	2/12/74
SLUICE TANK LIQUOR				
Flow (gpm)	141	140	140	140
Density (lbs/gal)	11.8	11.7	11.6	11.6
Solids (%)	63.5	64.0	64.7	65.2
BOILER LOADING (%)	106	106	107	108
SALT CAKE (lbs/min)	25	25	50	50
SULFIDITY - (DAILY AVG.%)	27.7	27.7	27.4	27.4
NOZZLE CONDITIONS				
Size	40	40	40	40
Pressure (PSI)	43	43	43	43
Liquor Temp. (°F)	250	250	250	248
Backsweep (°)	-7 to -18	-7 to -18	-5 to -20	-5 to -20
Sidesweep (°)	5L to 10R	5L to 10R	5L to 10R	5L to 10R
COMBUSTION AIR TEMP (°F)	230	230	230	230
AIR FLOW				
Primary (M lbs/hr)	155	155	155	155
(% of Total)	45	45	45	45
Secondary (M lbs/hr)	140	140	140	140
(% of Total)	40	40	40	40
Tertiary (M lbs/hr)	52	52	53	56
(% of Total)	15	15	15	15
Total (M lbs/hr)	347	347	348	351
EXCESS O_2 (%)	2.5	3.0	2.2	1.9
TRS AVG. (ppm)	1	1	9	3
SO_2 AVG (ppm)	7	18	8	5
STEAM FLOW (M lbs/hr)	218	216	222	223
BOILER EXIT CONDITIONS				
Temp (°F)	622	617	615	615
ACFM (1000 cu.ft./min)	238	234	224	238
DSCFM(1000 cu.ft./min)	71.1	69.9	69.8	72.0
Grain Loading(gr/DSCF)	6.98	7.05	5.99	7.4
Particulate Load(lbs/hr)	4250	4228	3579	4567
PRECIPITATOR INLET COND.				
Temp (°F)	385	385	385	385
ACFM(1000 cu.ft./min)	186	184	176	187
Volume @ 400°F	189	187	179	191
PRECIPITATOR OUTLET COND.				
Temp (°F)	365	365	365	380
ACFM (1000 cu.ft./min)	180	197	195	200
DSCF (1000 cu.ft./min)	69.6	79.4	77.6	79.0
Grain Loading(gr/DSCF)	0.0572	0.0655	0.0385	0.0356
Particulate Loading(lbs/hr)	31.7	41.4	25.6	24.1
PRECIPITATOR EFFICIENCY(%)	99.2	99.0	99.3	99.5

COMPLETE EPA TEST DATA FOR EXPANDED PROGRAM

TARGET CONDITIONS	Investigation of Salt Cake Addition Rates				
Boiler Loading (% of Design)	100	100			
Air Distribution (1°/2°/3°-%)	45/40/15	45/40/15			
Excess O_2 (%)	2.0-3.0	2.0-3.0			
TEST DATE	2/13/74	2/13/74			
SLUICE TANK LIQUOR					
Flow (gpm)	139	138			
Density (lbs/gal)	11.5	11.5			
Solids (%)	62.7	62.3			
BOILER LOADING (%)	102	100			
SALT CAKE (lbs/min)	75	75			
SULFIDITY - (DAILY AVG.%)	27.1	27.1			
NOZZLE CONDITIONS					
Size	40	40			
Pressure (PSI)	40	40			
Liquor Temp. (°F)	248	248			
Backsweep (°)	-5 to -20	-5 to -20			
Sidesweep (°)	5L to 10R	5L to 10R			
COMBUSTION AIR TEMP (°F)	235	235			
AIR FLOW					
Primary (M lbs/hr)	155	155			
(% of Total)	44	44			
Secondary (M lbs/hr)	140	140			
(% of Total)	40	40			
Tertiary (M lbs/hr)	55	55			
(% of Total)	16	16			
Total (M lbs/hr)	350	350			
EXCESS O_2 (%)	3.0	2.8			
TRS AVG. (ppm)	2	2			
SO_2 AVG (ppm)	55	26			
STEAM FLOW (M lbs/hr)	206	202			
BOILER EXIT CONDITIONS					
Temp (°F)	610	620			
ACFM (1000 cu.ft./min)	231	224			
DSCFM(1000 cu.ft./min)	70.5	68.2			
Grain Loading(gr/DSCF)	6.70	6.39			
Particulate Load(lbs/hr)	4047	3736			
PRECIPITATOR INLET COND.					
Temp (°F)	385	385			
ACFM(1000 cu.ft./min)	182	175			
Volume @ 400°F	185	178			
PRECIPITATOR OUTLET COND.					
Temp (°F)	372	375			
ACFM (1000 cu.ft./min)	190	187			
DSCF (1000 cu.ft./min)	76.2	74.1			
Grain Loading(gr/DSCF)	0.0509	0.0401			
Particulate Loading(lbs/hr)	33.2	25.5			
PRECIPITATOR EFFICIENCY(%)	99.2	99.3			